Game Changing Technologies are Changing the Game for Development

Draft Report for UNCTAD Technology and Innovation Review 2017
by Banning Garrett, May 31, 2017

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Game Changers Changing the Game

Harnessing technology will be critical if the world is to achieve the United Nations' 2030 Sustainable Development Goals (SDG). New and emerging technologies offer the potential for a world of far greater - and more equally shared - prosperity while also enhancing environmental sustainability and mitigating climate change. While new technologies such as artificial intelligence and gene editing pose dangers that must be addressed, without harnessing the great promise of emerging technologies, it will be virtually impossible to effectively address the world's biggest challenges and achieve the SDGs.

Emerging technologies provide fundamentally new and often underappreciated possibilities for economic development, environmental protection, education, and governance. Many of these technologies also offer the prospect of "better, cheaper, faster, and scalable" solutions and opportunities:

- "Better" because they more effectively solve problems, provide new capabilities and opportunities, and enable far greater efficiencies in use of natural and human resources.
- "Cheaper" because, like the microchip, they have become exponentially less expensive as they have become exponentially more powerful.
- "Faster" because new technology is diffusing ever more rapidly around the world, propelled by Internet connectivity and sharply falling prices.
- "Scalable" because new technologies often offer small-scale solutions that can be rapidly scaled up to meet such human needs as energy, food, clean water, health care, and education.

These four traits - better, cheaper, faster, and scalable - have led to the "democratization of technology" and to the process of innovation and development as increasingly a "bottom up" rather than "top down" process. Geography is no longer a limitation in the digital age. Advanced technologies are increasingly available to almost anyone, anywhere. Individuals and small groups can be the source of scientific discovery, technological innovation, and new business creation. A small startup company in any country can access not just the local market but also the global market. At the same time, these technologies are dependent on global "platforms of platforms," especially the Internet and the GPS system, and many of the platforms that are built on these fundamental systems, from social media and e-commerce to cloud computing services and the Internet of Things.

For governments seeking to meet the challenges of the SDGs with constrained resources, the new technologies provide the possibility of achieving "more with less" by supporting use of these new technologies and new innovation ecosystems that offer great flexibility and reduce both cost and risk. New solutions can be found and deployed much faster while failure can be identified sooner and triaged more quickly. Governments thus can minimize risk of technology investment "bets" that might prove to be high cost and high risk as well if they end in failure or result in obsolete technology by the time they come to fruition.

The pace of development and diffusion of technology is now so rapid that policy makers need to develop plans based on likely technological changes and their disruptive impact and new opportunities in the next few years and even decades. Hockey great Wayne Gretsky famously said "I skate to where the puck is going to be, not where it has been." Stanford bioengineering professor Drew Endy added that "the puck now has a little rocket motor attached and is accelerating." It could be added that contrary to simple laws of physics on ice, there are a range of possible and unpredictable trajectories for the technology puck. But the general direction can be seen with enough clarity that policy makers can look into the future to inform their near-term decisions - to both capitalize on opportunities and avoid investment in soon-to-be obsolete technologies and business models, thus wasting resources and making course corrections later more difficult and more expensive. A potentially expensive mistake, for example, would be to invest in a large, centralized coal or natural gas power plant with a projected amortized life-span of 40-50 years, when clean and scalable renewable energy is already cheaper and large-scale energy storage solutions are increasingly available. Similarly, self-driving cars are likely to be widely available in the next 10 years or so with transformative implications for urban planning, including infrastructure construction.

The accelerating pace of technological change is leading to increasing disruption of nearly all sectors of the economy as well as education, health care, and governance. These disruptions lead to opportunities for entrepreneurs to create new and more efficient businesses and for governments to solve intractable problems, including poverty, inadequate supplies of food, water, energy and other resources, and to address climate change, improve education, and enhance health care quality and distribution.

Many existing large corporations and SME's will adopt these new technologies and transform their business models. But accelerating technological change also threatens incumbent businesses, established organizations and bureaucracies, and vested interests throughout society that will oppose or fail to adapt to the rapidly changing technological landscape.

The new and emerging technologies are not only "game changers" but also offer the prospect of changing the game of how development is approached. They offer nations and cities the prospect of increasingly producing energy, food, and even products on demand and closer to where they are consumed. Governments can focus on building infrastructure, especially universally accessible and affordable broadband Internet connectivity, transportation systems, housing, education, health systems, energy systems, etc. But even these functions are all subject to positive disruption by technology and innovative business models to reduce their cost and "friction" -- that is, the ease and efficiency with which they connect the producer and consumer. These advances may require a government "re-think" before continuing to follow policies and pour resources into traditional ways of doing things. But the benefits of harnessing these technologies and innovations could be transformative in achieving the SDGs by 2030 to produce more prosperous, sustainable, healthy, and inclusive societies.

This report looks first at why the pace of technological development is accelerating. It then explores some of the key transformative technologies and their second and third order effects on society.

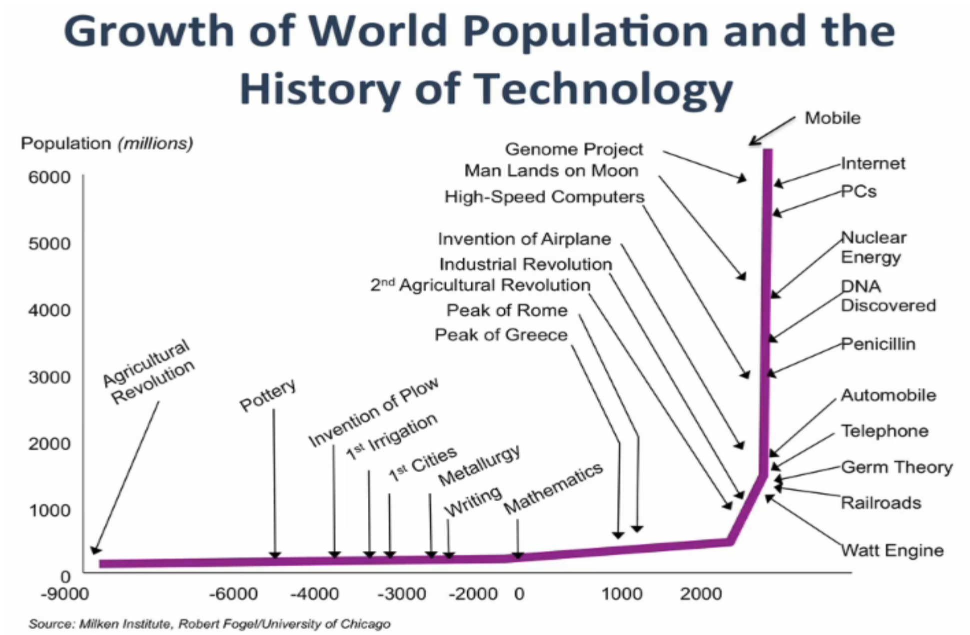
Technological Development is Accelerating

Technology has been advancing at an accelerating rate for a number of reasons that explain why it is likely to continue to do so in the future. Many experts expect that there will be more technological change in the next 20 years than in the last 50 years or more. This change will be highly disruptive but also will offer new solutions to global problems and opportunities to achieve the SDGs. There are six main factors accelerating the development and deployment of technology.

Technologies Building on Each Other

All technologies build on previous scientific discoveries and technological developments. As more technologies are developed, the rate of development of new technologies and their impact on society increases. Invention of the steam engine, for example, led to the transformation of transportation and of the factory, which in turn disrupted and transformed the world economy as well as society and geopolitics, setting the stage for further technological development. The harnessing of electricity led to the electrification of the factory and home, the creation of the telegraph,[1] the telephone, the radio, and television as well as modern electronics. These inventions, and myriads of others, transformed the world over the last century, radically changing business models for manufacturing, trade, government, military, and media.

[1] Tom Standage has dubbed the telegraph the Victorian Internet, which connected the world in real time for the first time in history, transforming trade, media, government, and public perceptions. See Tom Standage, *The Victorian Internet: The Remarkable Story of the Telegraph and the Nineteenth Century's On-line Pioneers*, (New York: Walker and Company, 1998).



Technological advances build on previous technological advances, accelerating technological development and prosperity enabling rapid population growth[2]

The pace of adoption of new technologies and their transformative impact has also accelerated. It was relatively slow in the 19th and most of the 20th centuries.[3] "It took 30 years for electricity and 25 years for telephones to reach 10% adoption [in the United States] but less than five years for tablet devices to achieve the 10% rate. It took an additional 39 years for telephones to reach 40% penetration and another 15 before they became ubiquitous. Smart phones, on the other hand, accomplished a 40% penetration rate in just 10 years, if we time the first smart phone's introduction from the

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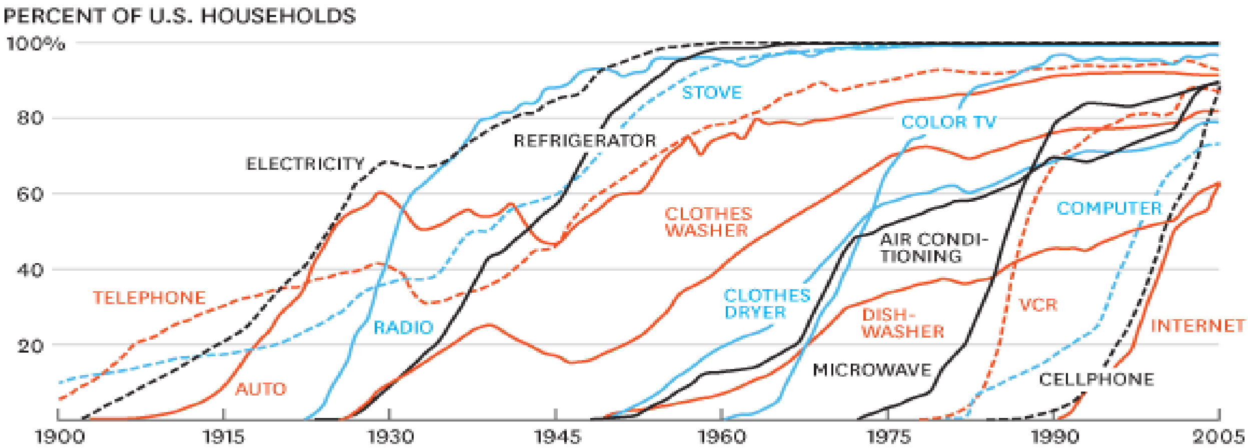
[2] Chart by Robert Fogel, adapted from original chart in "Catching up with the Economoy, The American Economic Review, Vol. 89, no. 1, March 1999, p. 2, http://www.jstor.org/stable/116977?origin=JSTOR-pdf&seq=3#page_scan_tab_contents.

[3] Robert Gordon notes that technology innovations after 1870 included an energy revolution with the exploitation of oil and the harnessing of electricity, and the development of the internal combustion engine. "These led in turn to the creation of machines: the electric light, the telephone, the radio, the refrigerator, the washing machine, the automobiles and the aircraft. They resulted in the transformation of lives via urbanization and the grid-connected home. These then drove an education revolution, as the economy demanded literate and disciplined workers." Robert Gordon, *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War* (Princeton: Princeton University Press, 2016). See Chapter 1, "The Ascent and Decent of Growth," pp. 1-23.

2002 shipment of the first BlackBerry that could make phone calls and the first Palm-OS-powered Treo model."[4] (See chart below.) [5]

CONSUMPTION SPREADS FASTER TODAY



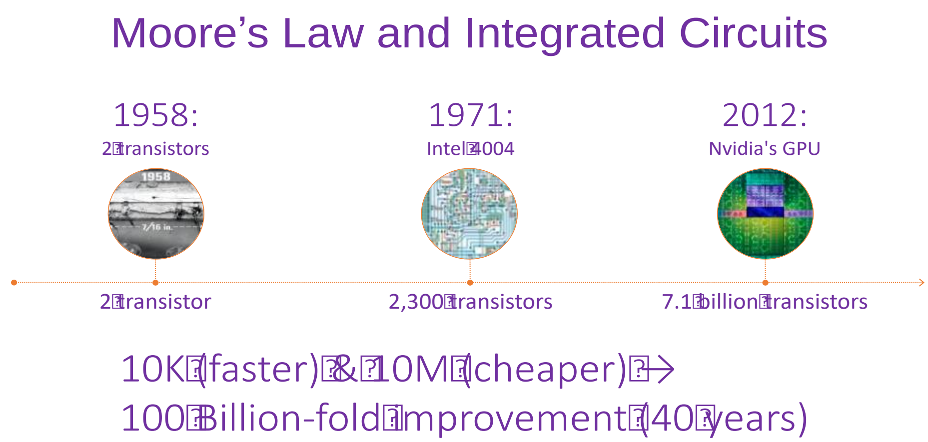
SOURCE MICHAEL FELTON, THE NEW YORK TIMES HBR.ORG

"Moore's Law"

The pace of development and adoption of technologies has been accelerated exponentially by "Moore's Law," named for Intel co-founder Gordon Moore. Moore predicted in 1965 that the processing power of microchips would double every 18-24 months. This "law" of exponential growth for microprocessors has held roughly true for fifty years, leading to a vast increase in capability. "Exponential technologies" are a large set of technologies that are developing at an exponential rather than linear rate. The impact of exponential growth is not readily apparent compared with additive, linear growth in early growth stages. But the impact of exponential growth soon becomes evident. Taking thirty, one-meter *linear* steps would result in moving thirty meters away as each step is only one additional meter. But by doubling the distance with each step, although the differences at first are not dramatic, the thirtieth exponential step is more than one billion meters -- or 25x around the earth. The exponential development of integrated circuits was the inspiration for Moore's Law and the signature technology for exponential growth in price-performance, which has experienced a 100 billion-fold

[4] Rita McGrath, "The Pace of Technology Adoption is Speeding Up," *Harvard Business Review*, November 25, 2013, https://hbr.org/2013/11/the-pace-of-technology-adoption-is-speeding-up. A similar chart for global adoption could not be found. The rate of adoption of cell phones in Africa vs North America, however, shows a similar time of ten years to 50% penetration, although Africa arrived at that point about 4 years after the US. However, Africa achieved 90% penetration in less than 14 years while it took North America about 17 years. As of 2013, Africa had 111% penetration - many people with more than one cell phone - while the North America was only 94%. See Cartesian, "The Rise of Mobile Phones: 20 Years of Global Adoption June 29, 2015, http://blog.cartesian.com/the-rise-of-mobile-phones-20-years-of-global-adoption. In the process, Africa took advantage of cellular technology to "leap frogged" developed nations by going directly to cell phones without first developing and extensive network of landlines.
[5] Rita McGrath, https://hbr.org/2013/11/the-pace-of-technology-adoption-is-speeding-up/.

improvement in 40 years, as shown in the chart below.[6] Other digital and digitally-enabled technologies as well as the microchip have exponentially decreased in cost while exponentially increasing in capability.



Moore's Law has driven exponential-price performance improvements throughout much of digitized realm. Whether - or how long - Moore's Law will continue in the development of microchips is a subject of debate among experts,[7] but advances in the impact of computing power are expected to continue to grow exponentially, powered by increasingly powerful algorithms (software), cloud computing with millions of servers, massive increases in data input analyzed by increasingly powerful machine learning and deep learning, new-type microprocessors, and improvements in quantum computing capabilities, which are likely to become increasingly commercialized in the next decade.[8]

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[6] Chart courtesy Singularity University.

[7] See, for example, Jonathan Borwein and David H. Bailey, "Moore's Law is Fifty Years Old, But Will it Continue?", Phys.Org, July 20, 2015, https://phys.org/news/2015-07-law-years.html; Sebastian Anthony, "Transistors will stop shrinking in 2021, but Moore's law will live on," ARS Technica, July 25, 2016, https://arstechnica.com/gadgets/2016/07/itrs-roadmap-2021-moores-law/; Tom Simonite, "Moore's Law is Dead. Now What?", MIT Technology Review, May 13, 2016, https://www.technologyreview.com/s/601441/moores-law-is-dead-now-what/. See also blog by Jensen Huang (CEO of Nvidia, maker of GPU chips that are powering AI), "AI is Eating Software," May 24, 2017, https://blogs.nvidia.com/blog/2017/05/24/ai-revolution-eating-software/?ncid=em-ded-nl-14694&mkt_tok=eyJpIjoiWVRjd05qSmtPR0ZtTm1aaSIsInQiOiJ2T0RjNXFEMzR2ZnJGZGhlNlVcL09oMUIrdEN1S25OMzQ3UVBTc2hyOW9Kcm04WXkxVDY3RE9SeU1telAxTkpqa1lHU2hMVkZVQ2hvQ0drVko1bmJ3dlpvbWJQRTBzdWtyY05jaCsrTE9LZnduOUFIaWIyMDd4bTlXYlQxalV6MnEifQ%3D%3D. Huang notes that GPUs (graphics processor units) are picking up where Moore's Law leaves off.

[8] Quantum computers are not just faster computers but rather approach problem solving in a fundamentally different way. For problems like decryption which have potentially billions or trillions of possible combinations, classical computers require testing combinations sequentially while a quantum computer could try all combinations simultaneously to find the key. One simulation by Microsoft indicated that a factoring problem that would take thirty-one thousand years to solve on a conventional computer could be resolved in a matter of seconds on a quantum computer. When general purpose quantum computers become available, much, if not most, current encryption, including on the Internet, could be

Impact of Moore's Law

"Your aging iPhone 5s has 1,000 the computational power of a Cray 1 supercomputer from the mid-70s at about 1/50,000th of the cost—a staggering fifty million times price/performance improvement. Sequencing the human gene took us a decade and $2.7 billion at the beginning of the 21st century. Today it takes us now mere hours and costs less than $1,000. And solar energy reached parity in its price/performance ratio to conventional sources of energy like coal—turning a scarce natural resource into something which will be abundantly available at little to no cost in the near-term future."[9] Pascal Finette, VP Startup Solutions, Singularity University

Technology Convergence

Technologies are converging and combining to produce new technologies, which will continue to accelerate the pace of technological change. Many technologists[10] argue that we are just at the beginning of a new acceleration in this technological change produced by platforms and enabling technologies as well as by combinations of technologies such as those making possible smartphones and autonomous vehicles, from advanced microprocessors and batteries, the Internet and GPS system to cellular communications, touch screens, and digital cameras and recorders.[11]

These technologies will lead to other combinatory technologies that will have ramifications throughout society and change peoples' lives - from how they communicate, work, and monitor their health, to how they organize businesses and government. These technology-induced disruptive changes will be happening in multiple sectors simultaneously and are likely to quickly spread globally, relentlessly resetting "the state of the art."

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subject to nearly instantaneous decryption. Quantum computers could also mark a new age in solving intractable problems. A quantum computer could simultaneously explore thousands of possible molecular combinations for a new material or drug to find the best combination in short order. It could solve such challenges as a creating a room temperature superconductor, accurately and in detail modeling climate change, and finding a catalyst to pull CO2 from the air. Although the first quantum computers will be very large, they could eventually be very small and provide immense new power to individuals and the Internet of Things.

[9] Pascal Finette, "Thriving in an Exponential World (and making a difference doing so!)," *Medium*, May 20, 2017, https://medium.com/@pfinette/thriving-in-an-exponential-world-and-making-a-difference-doing-so-b9dbc0e976aa.

[10] These technologists include: Kevin Kelly, *The Inevitable: Understanding the 12 Technological Forces that Will Shape our Future* (New York: Viking, 2016); Ray Kurzweil, *The Singularity is Near* (New York: Penguin Books, 2005); and Peter Diamandis and Steven Kotler, *Abundance: The Future is Better than You Think* (New York: Free Press, 2012) and *Bold: How to Go Big, Create Wealth, and Impact the World* (New York: Simon and Schuster, 2015).

[11] Thomas Friedman argues that a similar tipping point was reached about 10 years ago, when the iPhone was released, Facebook and Twitter appeared, Google bought YouTube and released the Android operating system, Amazon released the Kindle e-reader, Airbnb was conceived, and the Internet achieved one billion users. Thomas L. Friedman, *Thank You for Being Late: An Optimist's Guide to Thriving in the Age of Accelerations* (Farrar, Straus and Giroux: New York, 2016), pp 20-22.

Declining Costs

The cost of many products and services that are subject to digital technology continue to decline, especially as the marginal cost of production falls toward zero. A hard copy of a book, for example, will always entail the cost of materials, printing, shipping, etc., even if the marginal cost falls as more copies are produced. But the marginal cost of a second digital copy, such as e-book or a streaming video or song, is nearly zero as it is simply a digital file sent over the Internet, the world's largest copy machine.[12] This tendency toward "zero marginal cost" accelerates diffusion of technology, accelerating further technological development and innovation.

Other costs based on exponential technologies have also fallen dramatically, including the cost of communications. Long-distance and international telephone calls, which were often prohibitively expensive a generation ago, are now "free" domestically with basic cell phone service and "free" internationally with Skype, Google Hangouts, and other Internet-based services. Email, Facebook, Twitter, WhatsApp, etc., are all free with computer/mobile device connections to the Internet. Google provides access to vast stores of human knowledge, to GPS mapping, to cloud-based artificial Intelligence, and many other applications are free with Internet access. Just a generation ago film photography was expensive as each photo required purchase and development of film (about $1 per photo). Photos were also time consuming to have developed and were difficult to share. Now billions of people on the planet have access to free digital photography on their smartphones and, for free, can easily upload photos to Facebook and other social media sharing sites. Likewise, digitized entertainment has replaced hard copies - with CDs replaced by iTunes, Spotify and Pandora; DVDs replaced by streaming services like Netflix and Amazon; and hardbacks and paperbacks by e-books from Amazon, Google, and Apple.

Moreover, the cost of digitally-enabled devices tends to drop precipitously. The most spectacular example is the smartphone, which has capabilities if purchased separately a generation ago would cost more than $900,000 in 2011 ($977,000 in 2017 dollars), as shown in the chart below.[13] Now those capabilities and many more are free with the purchase of the smartphone. And the cost of smartphones is expected to fall dramatically over the next five years to as little as $30, "putting in the hands of all but the poorest of the poor the power of a connected supercomputer," which by 2023 "will have more computing power than our own brains."[14]

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[12] See Jeremy Rifkin, *The Zero Marginal Cost Society*, (New York: Palgrave Macmillan, 2014), Part II, pp. 69-154.
[13] From Peter Diamandis and Steven Kotler, *Abundance: The Future is Better than You Think* (New York: Free Press, 2012), p. 289.
[14] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), p. 15.

Dematerialization

>$900,000 worth of applications in a smart phone today

Application	$ (2011)	Original Device Name	Year*	MSRP	2011's $
1. Video conferencing	*free*	Compression Labs VC	1982	$250,000	$586,904
2. GPS	*free*	TI NAVASTAR	1982	$119,900	$279,366
3. Digital voice recorder	*free*	SONY PCM	1978	$2,500	$8,687
4. Digital watch	*free*	Seiko 35SQ Astron	1969	$1,250	$7,716
5. 5 Mpixel camera	*free*	Canon RC-701	1986	$3,000	$6,201
6. Medical library	*free*	e.g. CONSULTANT	1987	Up to $2,000	$3,988
7. Video player	*free*	Toshiba V-8000	1981	$1,245	$3,103
8. Video camera	*free*	RCA CC010	1981	$1,050	$2,617
9. Music player	*free*	Sony CDP-101 CD player	1982	$900	$2,113
10. Encyclopedia	*free*	Compton's CD Encyclopedia	1989	$750	$1,370
11. Videogame console	*free*	Atari 2600	1977	$199	$744
Total	**free**				**$902,065**

*Year of Launch

In the future, there will likely be further dramatic cost reductions for a wide range of basic needs. "Powered by developments in exponential technologies, the cost of housing, transportation, food, health care, entertainment, clothing, education and so on will fall, eventually approaching, believe it or not, zero," which, constitute the majority of expenditures in countries as varied as the US, China, and India.[15] The cost of transportation, for example, could plummet as fully autonomous services make possible access rather than ownership for cars, eliminating the cost of purchase, insurance, parking, maintenance, fuel, and even parking tickets. "Today, average Americans spend almost two of their eight hours at work paying off their car, which they need to get to that job."[16]

Exponential cost declines are also affecting the energy sector, especially the plummeting cost of solar power, which has already become cost-competitive with coal and natural gas, and the declining cost of electric vehicles and batteries. The cost of solar cells has dropped by more than a factor of 100 in the last 40 years, from $76.67/watt in 1977 to $0.029/kwh in 2017.[17] Solar cells and storage batteries are expected to continue to improve in efficiency while decreasing in cost, further fueling an

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[15] According to Peter Diamandis, "Why the Cost of Living Is Poised to Plummet in the Next 20 Years," Singularity Hub, July 18, 2016, http://singularityhub.com/2016/07/18/why-the-cost-of-living-is-poised-to-plummet-in-the-next-20-years/. For a US government estimate of annual costs for Americans of these expenditures, "Average annual expenditures and characteristics of all consumer units, Consumer Expenditure Survey, 2013-2014," see http://www.bls.gov/cex/2014/standard/multiyr.pdf. On the declining cost of living, see also "What's the Future of Jobs," *Edge Perspectives with John Hagel*, September 2016, http://edgeperspectives.typepad.com/edge_perspectives/2016/09/whats-the-future-of-jobs.html.

[16] Robin Chase, "Self-driving Cars Will Improve Our Cities. If They Don't Ruin Them." *Backchannel*, August 10, 2016, https://backchannel.com/self-driving-cars-will-improve-our-cities-if-they-dont-ruin-them-2dc920345618?imm_mid=0e6d3a&cmp=em-business-na-na-newsltr_econ_20160819#.9ctd4jwx7.

[17] Pilita Clark, "The Big Green Bang: How Renewable Energy Became Unstoppable," May 18, 2017, https://www.ft.com/content/44ed7e90-3960-11e7-ac89-b01cc67cfeec?emailId=591ebc34b0920f0004f4f85a&segmentId=3934ec55-f741-7a04-feb0-1ddf01985dc2.

energy transition.[18] Moreover, solar is now the cheapest energy in the sunniest parts of the world.[19] In addition, electric vehicles could rapidly replace fossil-fuel-powered vehicles as they will be cheaper to make and maintain. The rapid development of electric cars has supported accelerating development of battery technology and reduction in battery cost. "Electric cars that were hard to even buy eight years ago are selling at an exponential rate," the *Financial Times* reported in May 2017, "in the process driving down the price of batteries that hold the key to unleashing new levels of green growth."[20] By 2030, one expert predicts, electric vehicles with a 200+ mile range may be cheaper that the cheapest car sold in the United States in 2015.[21]

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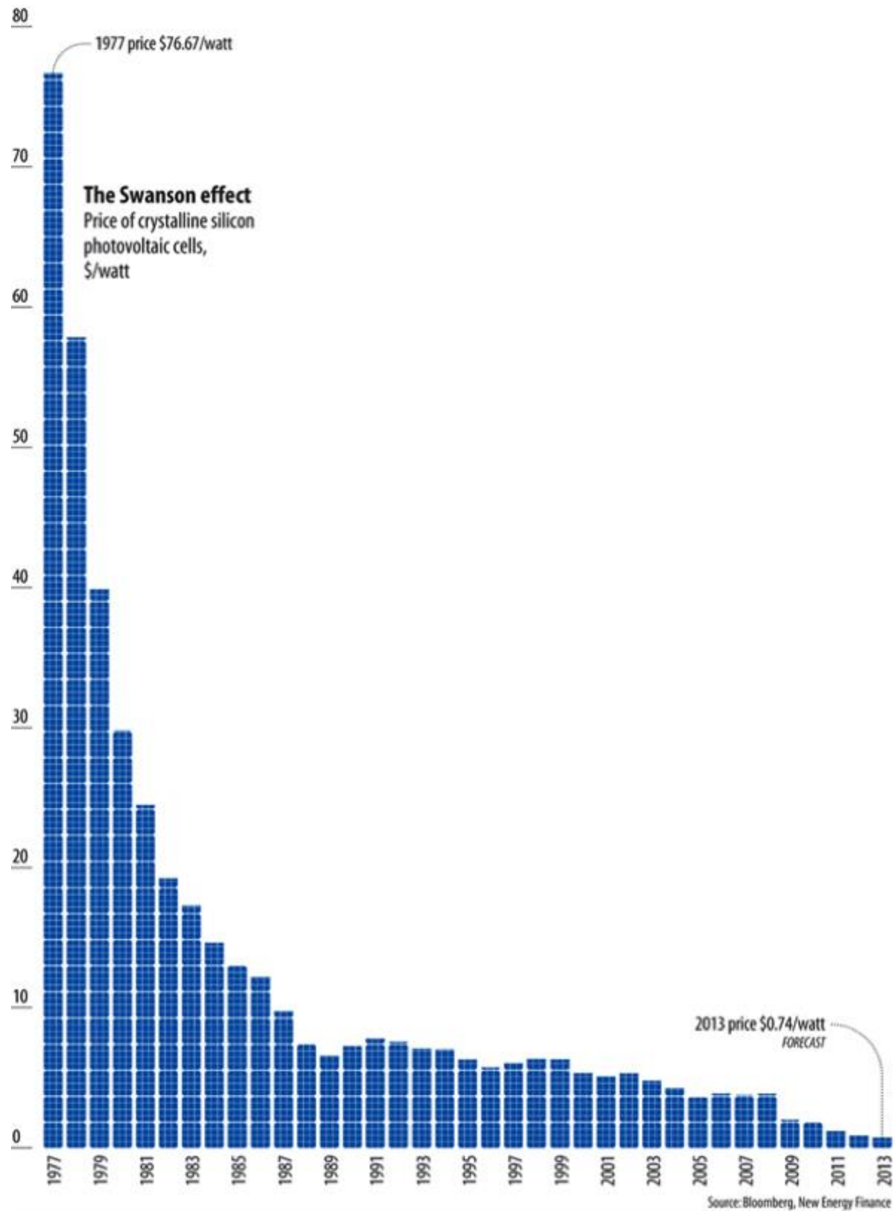
[18] Peter Diamandis, "Disrupting Energy," QTech Blog (no date), http://www.diamandis.com/blog/disrupting-energy.
[19] See Jason Dorrier's interview with Ramez Naam, "Solar Is Now the Cheapest Energy There Is in the Sunniest Parts of the World," Singularity Hub, 18 May 2017, https://singularityhub.com/2017/05/18/solar-is-now-the-cheapest-energy-there-is-in-the-sunniest-parts-of-the-world/?utm_content=buffercf0fa&utm_medium=social&utm_source=facebook-su&utm_campaign=buffer.
[20] Pilita Clark, "The Big Green Bang: How Renewable Energy Became Unstoppable," May 18, 2017, https://www.ft.com/content/44ed7e90-3960-11e7-ac89-b01cc67cfeec?emailId=591ebc34b0920f0004f4f85a&segmentId=3934ec55-f741-7a04-feb0-1ddf01985dc2.
[21] Peter Diamandis, "Disrupting Energy," QTech Blog (no date), http://www.diamandis.com/blog/disrupting-energy. See also Karla Lant, "Experts Predict EVs Could Be Cheaper than Gas-Powered Cars by 2030," https://futurism.com/experts-predict-evs-could-be-cheaper-than-gas-powered-cars-by-2030/.



Multiple Platforms

These platforms have been built on the two “platforms of platforms,” the Internet, enabling global mobile connectivity, and the GPS system, which functions as both the essential timing clock of the Internet and a source of geolocation for millions of apps, from Google maps and Waze, to maps on apps directing you to your local restaurant or theater. These two platforms have enabled building new platforms driving further technological innovation and creation of businesses based on these platforms.

Other "platforms" built on these two underlying platforms include Google,[22] Facebook,[23] Baidu, Tencent, WeChat, WhatsApp, Snapchat, Twitter, Alibaba, and many thousands more. The ecosystem of several million "apps" have been built on smartphone platforms, including Apple IOS and Android. This has led to the creation of millions of startup businesses exploiting these platforms by building apps and to the use of these apps daily by billions of people around the world. Uber and Didi ride-hailing services, and Airbnb[24] and Tujia home-sharing services[25] are platforms based on apps and mobile connectivity, which have led to employment of hundreds of thousands of drivers and income for more than a million property renters. Amazon Web Services, Google Cloud Platform, Microsoft Azure, and other cloud computing platforms provide global access to cheap and ubiquitous cloud-based computation, software-as-a-service, and artificial intelligence. Other exponential technologies are also functioning as platforms, including drones, robotics, computational biology, 3D printing, and the Internet of Things.

The technology of the Internet and the many platforms built on this "platform of platforms" are creating new opportunities for entrepreneurs all over the world to start new technology-based companies and for these startups as well as existing SMEs to reach global markets at a time when globalization in trade and capital flows is stalling. Since the financial crisis in 2008, global trade has flattened and cross-border capital flows have declined, but there has been an exponential increase in the flows of data and information with significant implications for job creation in developing countries and connectivity of their economies to the global market place and global knowledge,

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[22] "Google's search and advertising tools helped provide $165 billion of economic activity for 1.4 million businesses, website publishers and non-profits," in the United States in 2015, according to "The web is working for American businesses. Google is helping." "Economic Impact, 2015," Google, https://economicimpact.google.com/#/. The report compiled by Google claims that: 1.4 million nationwide businesses and non-profits benefitted from using Google's advertising tools, AdWords and AdSense, in 2015.1 75% of the economic value created by the Internet is captured by companies in traditional industries. $165 billion of economic activity Google helped provide nationwide for businesses, website publishers and non-profits in 2015. Two times as many jobs and twice as much revenue through exports were created by web-savvy SMBs. 97% of Internet users look online for local products and services. 9 out of 10 part-time business owners rely on the Internet to conduct their businesses.

[23] Facebook commissioned Deloitte to estimate the economic impact it enabled in 2014 around the world. The report estimated that "through the channels of marketers, app developers and providers of connectivity, Facebook enabled $227bn of economic impact and 4.5m jobs globally in 2014. These effects accrue to third parties that operate in Facebook's ecosystem, and exclude the operations of the company itself. Deloitte, "The global economic impact of Facebook: Helping to unlock new opportunities," http://www2.deloitte.com/uk/en/pages/technology-media-and-telecommunications/articles/the-global-economic-impact-of-facebook.html. Deloitte, "Facebook's Global Economic Impact," January 2015, http://www2.deloitte.com/uk/en/pages/technology-media-and-telecommunications/articles/the-global-economic-impact-of-facebook.html, p. 1.

[24] Airbnb enables the more efficient use of existing inventory of housing as well as generating income for the owners of the rental properties - in effect, jobs marketing, servicing and managing these properties. 40,000 units were provided in Rio de Janeiro during the 2016 Olympics, reducing the need to build more hotels. During the World Cup, two years earlier, 120,000 "hotel rooms" were provided by Airbnb around Brazil.

[25] "An Overview of China's "Airbnb": Xiaozhu, Tujia, Zhubaijia," China Internet Watch, March 4, 2017, https://www.chinainternetwatch.com/14626/chinas-airbnbs/.

education, and entertainment. “Remarkably, digital flows—which were practically nonexistent just 15 years ago—now exert a larger impact on GDP growth than the centuries-old trade in goods,” according to a 2016 study by the McKinsey Global Institute (MGI).”[26]

These cross-border flows are no longer largely confined to advanced economies and their large multinational companies. Rather, MGI notes, “a more digital form of globalization has opened the door to developing countries, to small companies and start-ups, and to billions of individuals.” About 12 percent of the global goods trade is conducted via international e-commerce, according to MGI, “as tens of millions of small and midsize enterprises worldwide have turned themselves into exporters by joining e-commerce marketplaces such as Alibaba, Amazon, eBay, Flipkart, and Rakuten.” Moreover, “even the smallest enterprises can be born global: 86 percent of tech-based start-ups surveyed by MGI report some type of cross-border activity. Today, even the smallest firms can compete with the largest multinationals.”

MGI notes that connectivity also has grown exponentially in the last decade. The amount of cross-border bandwidth that is used has grown 45 times larger since 2005 and is projected to increase by an additional nine times over the next five years “as flows of information, searches, communication, video, transactions, and intracompany traffic continue to surge.” The MGI report notes that “virtually every type of cross-border transaction now has a digital component “data flows enable the movement of goods, services, finance, and people.”

The world’s population is directly connected to this data flow. The number of mobile broadband subscriptions worldwide by the fourth quarter of 2016, according to Ericsson, was 4.3 billion (57% of the world’s 7.5 billion population as of April 2017) with 7.7 billion total mobile phone subscriptions (with about 5.2 billion individual subscribers as many people, especially in Asia, have more than one mobile phone).[27] Ericsson predicts that by 2021, there will be 9 billion mobile subscriptions, 7.7 billion broadband mobile subscriptions, and 6.6 billion smartphone subscriptions, including an additional 730 million subscribers in the Middle East and Africa and additional 230 million in Latin America. By 2025, nearly every person on the planet will have access to the extraordinary capabilities of internet-connected mobile devices with supercomputer capabilities.[28] Space X, Facebook, Google, and a number of other technology companies plan to deploy systems in the next few years to bring broadband Internet to every person on the planet using small satellites, balloons, drones, and other delivery systems. Nearly 2 billion people use Facebook at least once a month and at least once

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[26] James Manyika, Susan Lund, Jacques Bughin, Jonathan Woetzel, Kalin Stamenov, and Dhruv Dhingra, “Digital Globalization: The New Era of Global Flows,” McKinsey Global Institute Report, February 2016, http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/digital-globalization-the-new-era-of-global-flows.

[27] Mobile Subscriptions, Ericsson Mobility Report, 4th Quarter 2016, https://www.ericsson.com/assets/local/mobility-report/documents/2017/emr-interim-february-2017.pdf.

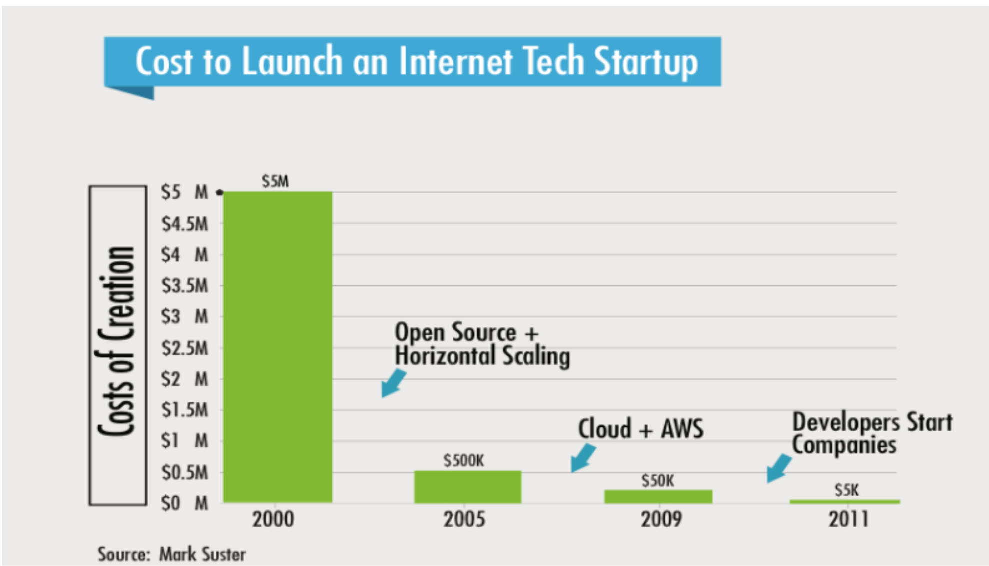
[28] Mobile Subscriptions, Ericsson Mobility Report, 1st Quarter 2016, https://www.ericsson.com/mobility-report/mobile-subscriptions.

a day, 1.2 billion people use Facebook and one billion people use WhatsApp and Facebook messenger, among other social media.[29]

[29] http://www.smartinsights.com/social-media-marketing/social-media-strategy/new-global-social-media-research/.

Reduced "Cost of Entry"

These platform technologies combined with exponential technologies have "democratized" access to technology and have led to a sharp reduction in the "cost of entry" for scientific experimentation and for entrepreneurs to create new businesses. This has led to the proliferation of hundreds of thousands of startups all over the world that are leveraging the Internet, cloud computing, artificial intelligence, 3D printing, drones, apps, and genomics and computational biology. The cost of starting an internet business has dropped precipitously toward zero as developers no longer require a major investment in servers and software but rather can rely on cloud-based computing power and open-source software, sharply reducing costs and labor requirements.[30] One estimate suggests that this cost dropped *1,000 fold* in the decade from 2000 to 2011, from about $5 million to about $5,000 (see figure below). By 2017, the cost of building an app or Internet company has fallen by another order of magnitude, to only hundreds of dollars, propelled by cloud-based open source software and cloud computing, and increasing access to artificial intelligence applications. The main cost or a startup is a laptop computer, an Internet connection, "paying for use" of cloud-based computing, if necessary, and the labor of the entrepreneur.



1,000-fold reduction in cost from 2000 to 2011[31]

For a startup in the world of "atoms" (or material products) as well as "bits" (or digital products and services), the additional cost beyond a computer and Internet

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[30] Cost of storing one gigabyte of data in the cloud on Amazon Web Services plummeted from $19.00 per month in 2000 to $ 0.16 per month in 2011 (https://www.slideshare.net/The_Cambrian_Cloud/diminishing-startup-costs) and to less than $ 0.03 in 2016 (https://cloud.google.com/storage/pricing).

[31] https://www.linkedin.com/pulse/entrepreneurs-government-drive-innovation-heres-why-peter-diamandis. Diamandis chart based on estimates by Mark Suster, prominent blogger in the VC world (https://en.wikipedia.org/wiki/Mark_Suster). See also https://www.slideshare.net/The_Cambrian_Cloud/diminishing-startup-costs.

connection could be as little as a few hundreds of dollars for a 3D printer (see box) to start a company to produce material products. Digitization of biology has also led to an order of magnitude decline in the cost of biotech development, including the ability to design experiments digitally and upload the digital file to cloud-based laboratories that will conduct the experiment for a small fraction of the cost of acquiring laboratory equipment and hiring lab technicians.[32]

From Invention to Manufacturing: A Democratized and Distributed Alternative to Centralized, Mass Production?

The exponential process powering technological change in the digital world is increasingly occurring in the digital-to-physical world as well. Democratization of technology is leading to distributed manufacturing, from invention and prototyping to production, marketing and distribution. This technological shift offers unprecedented new possibilities for individuals and small groups of inventors to progress from idea to finished and distributed product with low cost and low risk - and to do so almost anywhere in the world.

In the traditional industrial model, the path from a new invention or product idea to its manufacturing, marketing and distribution has been a long and expensive process, often involving many different companies. For example, an individual inventor may have an idea for a new product. A design firm would then be hired (or tasked within a company) to make a full engineering blueprint for the product. The design then would be passed to a prototyping company (or shop) that would spend weeks or months using various machines to produce prototypes until satisfied that a potentially marketable design had been created. Next, a factory would have to be retooled or built to produce the product, and then have to produce at sufficient scale to hope to recoup the investment and turn a profit. Once the product has been produced, the manufacturer would need to arrange for distribution, marketing, and sales.

This entire process would involve many different organizations (even within one company), probably many months from idea to production, many workers and managers, and millions of dollars in costs - and all this before any of the products were sold and with no guarantee the product would even sell much less

[32] http://nordicapis.com/exploring-the-cloud-laboratory-advances-in-biotech-science-as-a-service/. The article that two cloud-based lab companies, *Transcript* and *Emerald Cloud Computing*, “are both thriving in this ambitious quest to usher in a new era of **life sciences entrepreneurship**, in which a small cash-strapped team can create and manage a profitable pharmaceutical company from a laptop, much like what can be achieved today in web startups. … Their aim is to change the way research is done, dramatically offsetting the ever-increasing costs of clinical trials, automating tedious lab work, and accelerating research by running experiments in parallel. They currently offer common protocols like PCR for genotyping animal samples, DNA/RNA synthesis, and protein extraction. More complex or custom experiments are still better delegated to a CRO [Contract Research Organizations], but in the future all experiments may be conducted in this way.”

be profitable. In short, the traditional model is a high-cost and time-consuming process. And it is high-risk, as the failure of many products and companies can attest.

By employing new technology, the entire process from idea, design, and prototyping, to manufacturing, marketing and distribution, could be done by even one individual.[33] She could use her computer and the Internet to download open source design software to create a prototype. She could then send the prototype to her 3D printer (run on open source software) to start experimenting with prototypes, each produced in a matter of hours, until a potentially marketable design was produced. She could then decide whether to sell the design itself as an STL file directly on the Internet or could advertise on the Internet to sell the finished product and then produce the product on demand and ship the product directly to the buyer. A third alternative for her would be to send her design to a company like Shapeways[34] that could print her design on demand and ship it to the customer. The product could be customized for each customer since each printing can be unique and there is no cost benefit to mass producting the same item. The product or the design file could also be marketed globally.

Thus, one person with a very minimal investment of a few thousand dollars in the computer, Internet connection, 3D printer and materials, could be an inventor, prototyper, manufacturing, marketer, and distributor. In this low-cost, low-risk business model, if the product does not sell, the inventor has lost mostly time and could iterate a new design for the product or develop an entirely new product using the same equipment. In addition, she could crowdsource financing of her project through Kickstarter and reach out to the "maker" community to crowdsource design ideas.

This is an extreme case, but it illustrates the new reality that individuals or small teams of entrepreneurs can utilize this new distributed-production model to leverage new technologies and technology platforms, from the Internet and cloud computing to inexpensive 3D printers, to build a business from scratch. The power of this approach will be boosted by the availability of artificial intelligence

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[33] For more on this process, see Chris Anderson, *Makers: The New Industrial Revolution* (New York: Crown Business, 2012). For charts of free and inexpensive services available to individual startups, see https://www.slideshare.net/The_Cambrian_Cloud/diminishing-startup-costs, slides number 16, 17, and 18.

[34] https://www.shapeways.com/. Carbon, a new 3D printing company that emerged in 2015, has unveiled a new process that prints 25-100 times faster than conventional 3D printers and allows for going direct from design to final product without prototyping. Carbon announced that this year they will print 100,000 pairs of soles for Addidas running shoes. While their printers are expensive at this point, they are pointing toward a future of even more capability for the individual entrepreneur to become an all-in-one designer-manufacturer-and marketer. See Vanessa Bates Ramirez, "Carbon's Bold Mission to Finally Dematerialize Manufacturing," Singularity Hub, 22 May 2017, https://singularityhub.com/2017/05/22/carbons-bold-mission-to-finally-dematerialize-manufacturing/?utm_content=buffer8ebc9&utm_medium=social&utm_source=facebook-hub&utm_campaign=buffer

as a utility in the cloud, an explosion new materials especially for use in 3D printers, and an exponential improvement and cost reduction in 3D printers themselves.

Technologies build on each other, so as more technologies have been developed over the millennia, the rate of development of new technologies has increased. This pace of development and adoption of technologies has been accelerated exponentially in the last half century by "Moore's Law." Exponential technologies have been converging and combining to further accelerate the pace of technological change. While the capabilities of these technologies have increased exponentially, their costs have fallen at dramatically, especially for products and services subject to digitization, thus making possible rapid diffusion around the world on technology platforms, further accelerating technological development and innovation. This has enabled building of new platforms driving further technological innovation and creation of new businesses based on these platforms. These platform technologies also have led to a sharp reduction in the "cost of entry" for scientific experimentation and for entrepreneurs to create new businesses, which has spurred the creation of hundreds of thousands of startups all over the world. This rapid proliferation of digital entrepreneurship will in turn accelerate technological development.

The Fourth Industrial Revolution

"The First Industrial Revolution used water and steam power to mechanize production. The Second used electric power to create mass production. The Third used electronics and information technology to automate production. Now a Fourth Industrial Revolution is building on the Third, the digital revolution that has been occurring since the middle of the last century. It is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres. There are three reasons why today's transformations represent not merely a prolongation of the Third Industrial Revolution but rather the arrival of a Fourth and distinct one: velocity, scope, and systems impact. The speed of current breakthroughs has no historical precedent. When compared with previous industrial revolutions, the Fourth is evolving at an exponential rather than a linear pace. Moreover, it is disrupting almost every industry in every country. And the breadth and depth of these changes herald the transformation of entire systems of production, management, and governance."[35] - *Klaus Schwab, Founder and Executive Chairman, World Economic Forum*

Transformative Technologies

The two key features of exponential technologies have been digitalization and connectivity. With the entire global population rapidly becoming connected through the mobile internet, extraordinary new opportunities are expanding for exploiting the vast array of new and emerging digitally-enabled exponential technologies to address the SDGs in virtually every country in the world.

[35] Klaus Schwab, "The Fourth Industrial Revolution: what it means, how to respond," World Economic Forum, 14 January 2016, https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.

This digital connectivity is continuing to expand and deepen, including with development and increasing use of virtual reality (VR) and augmented reality (AR). But we are now moving beyond the era of digital-digital interconnectivity, to an era that includes rapid advances in digital-material-digital interconnectivity and interaction as well. This world of the Internet of Things (IoT)[36] includes increasing interconnectivity between machines (M2M), which General Electric calls the "industrial Internet," and between machines and humans that includes interaction mediated by artificial intelligence (AI). They are all enabled by digital technologies in smartphones, 3D printers, autonomous vehicles, and drones. And they all depend on the ability to connect to the Internet (even if their operation does not require that they are always connected).

Beyond the Tricorder

Not only are individual technologies on an exponential curve of improvement, but the combination of key digital technologies is at an "inflection point," according to MIT researchers Erik Brynjolfsson and Andrew McAffee, who maintain that "we are entering a second machine age."[37] Brynjolfsson and McAffee note that the convergence of exponential technologies can surpass the expectations of science fiction: "On the *Star Trek* television series, devices called tricorders were used to scan and record three kinds of data: geological, meteorological, and medical. Today's consumer smartphones serve all these purposes; they can be put to work as seismographs, real-time weather radar maps, and heart- and breathing-rate monitors. And, of course, they're not limited to these domains. They also work as media players, game platforms, reference works, cameras, and global positioning system (GPS) devices. On *Star Trek*, tricorders and person-to-person communicators were separate devices, but in the real world the two have merged in the smartphone..."[38]

Exponential technologies are a set of interconnected and mutually-complementary enabling technologies that are frequently combining and recombining to enable more new technologies and capabilities in energy, transport, health, education, manufacturing, and government. These disruptive changes are driven by the dramatic decrease in computing and connectivity costs that is "poised to drive amazing changes in every field that is exposed to technology; that is in *every* field. The same trend applies to the cost of the already cheap sensors that are becoming the backbone of the web of connected devices" of the Internet of Things.[39]

A suite of exponential technologies, from the Internet and GPS system to cellular communications and touchscreens, made possible the creation of the iPhone in 2007.

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[36] Sometimes referred to as the "Internet of Everything," the "Industrial Internet," and, for agriculture, the "Internet of Farm Things."
[37] Erik Brynjolfsson and Andrew McAffee, The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies (New York: W.W. Norton, 2014), chapter 1.
[38] Bryjnolfsson and McAffee, chapter 2.
[39] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), p. 11.

The same set of technologies - with improvements over the last decade and combined other new or improved technologies - is making possible autonomous vehicles and drones. Technologies like artificial intelligence are becoming ubiquitously embedded in a huge range of other technologies and products, making them “smarter,” more efficient, and more interactive with humans. The “Internet of Things” is exponentially expanding with more than 15 billion “things” (from smart sensors to smartphones, laptops and other computing devices) currently connected to the Internet, a number that could triple by 2020 and reach a trillion or more by 2030. The IoT includes a wide range of devices connected to the Internet, from simple sensors to smartphones and machines. Jansen Huang, CEO of Nvidia, the premier producer of computer chips for AI (GPUs), maintains that “deep learning’s ability to detect features from raw data has created the conditions for a Cambrian explosion of autonomous machines – IoT with AI. There will be billions, perhaps trillions, of devices powered by AI.”[40]

> “My smartphone is several thousand times more powerful and millions of times less expensive than the $11 million IBM 7094 computer I used when I was an undergraduate at MIT in 1965. But that’s not the most interesting thing about my phone. If I want to multiply computational and communication power by 10,000—that is to say, if I need to access 10,000 computers—I can do that in the cloud, and that happens all the time. We’re not even aware of it. Do a complex language translation, a complex search or many other types of transactions, and you’re accessing thousands of computers while you sit quietly in a park somewhere. Over the next couple of decades we’re going to make ourselves smarter by integrating with these tools.”[41]
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> – ***Ray Kurzweil***, Director of Engineering, Google

Autonomous vehicles, including drones as well as automobiles and trucks, have been made possible by bringing together a myriad of exponential technologies. Some of these technologies had converged in 2007 to make possible the iPhone and other smartphones and have continued to exponentially improve and to exponentially decline in cost. The smartphone technologies that are especially critical to autonomous vehicles include microprocessors, sensors, digital cameras, mobile internet connectivity, cloud computing, artificial intelligence, and solid-state batteries. Other technologies essential to building AVs also have become cheaper and more capable, including lidar, radar, wireless networking, nanosensors, and other Internet of Things technologies. Many of these same technologies are leading to a transformation in medicine and health care as well as energy production, storage, and distribution. And as solar energy becomes far cheaper and scalable, it will lead to increasing ability to provide for clean water for production of food as well as human use.

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[40] From blog by Jensen Huang (CEO of Nvidia, maker of GPU chips that are powering AI0, “AI is Eating Software,” May 24, 2017, https://blogs.nvidia.com/blog/2017/05/24/ai-revolution-eating-software/?ncid=em-ded-nl-14694&mkt_tok=eyJpIjoiWVRjd05qSmtPR0ZtTm1aaSIsInQiOiJ2T0RjNXFEMzR2ZnJGZGhlNlVcL09oMUIrdEN1S25OMzQ3UVBTc2hyOW9Kcm04WXkxVDY3RE9SeU1telAxTkpqa1lHU2hMVkZVQ2hvQ0drVko1bmJ3dlpvbWJQRTBzdWtyY05jaCsrTE9LZnduOUFIaWIyMDd4bTlXYlQxalV6MnEifQ%3D%3D.

[41] “Reinvent Yourself: The Playboy Interview with Ray Kurzweil,” 19 April 2016, http://www.playboy.com/articles/playboy-interview-ray-kurzweil.

3D printing is a rapidly-improving and disseminating Internet-enabled "general purpose technology" being used for an extraordinary range of purposes, from printing human tissue and eventually human organs, to printing housing, bridges, and critical parts of jet engines and rockets.

Artificial Intelligence Increasingly Ubiquitous

In the last few years, artificial intelligence (AI) has become the focus of attention for technologists, investors, governments, and futurists. AI was first proposed more than 60 years ago and has had periods of progress and stagnation when it has been virtually sidetracked as other technologies improved exponentially. But recent breakthroughs have led to major advances in AI, driven by machine learning (ML) and deep learning (DL) which in turn have been made viable by access to huge amounts of big data, cheap and massive cloud computing, and advanced microprocessors.[42] AI has advanced image recognition to exceed human capabilities, greatly improved language translation, including voice translation through natural language processing (NLP), and proven more accurate than doctors in diagnosing some cancers. Computer recognition of images cats was made possible, for example, by ML and DL being "taught" by processing massive data sets of millions or even billions of cat photos. Similarly with translations, AI has simply sorted through billions of translations to continuously improve its translation capability.

Since AI is constantly "learning" through processing data, the more data it processes, the smarter it gets. Google is using the *3 billion daily* queries to tutor its AI. "Rather than use AI to make it search better," according to technology writer Kevin Kelly, "Google is using search to make its AI better. Every time you type a query, click on a search-generated link, or create a link on the web, you are training the Google AI."[43] The result, Kelly predicts, is that "with another 10 years of steady improvements to its AI algorithms, plus a thousandfold more data and hundred times more computing resources, Google will have an unrivaled AI," and AI, not search, will be its main product. Amazon, IBM, Apple, and other big technology companies that are amassing and processing huge amounts of data with AI algorithms will also have highly developed AIs, all available in the cloud.

These AIs will be ubiquitous and largely free over the Internet as Siri, Apple's AI assistant is now on the iPhone and Google Assist on Android and iOS devices. Amazon's Alexa is widely used and constantly improving based on the millions of queries it receives per day. All of these AIs will be increasingly available in a wide range of devices, from automobiles to refrigerators. Kelly forecasts that this will lead AI to have a greater transformative impact than the industrial revolution. "It is hard to imagine anything that would 'change everything' as much as cheap, powerful,

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[42] See Kevin Kelly, *The Inevitable: Understanding 12 Technological Forces that Will Shape Our Future* (New York: Viking, 2016), pp. 38-40.
[43] Kevin Kelly, *The Inevitable: Understanding 12 Technological Forces that Will Shape Our Future* (New York: Viking, 2016), p. 43.

ubiquitous artificial intelligence. ... Even a very tiny amount of useful intelligence embedded into an existing process boosts its effectiveness to a whole other level. The advantages gained from cognifying inert things would be hundreds of times more disruptive to our lives than the transformations gained by industrialization."[44] In fact, Kelly adds, "the business plans of the next 10,000 startups are easy to forecast: *Take X and add AI*. Find something that can be made better by adding online smartness to it." And for the most part, this AI will be "free" to anyone, anywhere, who is connected to the Internet, thus enabling companies, governments, and startups anywhere to "add AI" to almost any product or service.

Autonomous Vehicles, Drones, and Robots Powered by AI

These recent advances in artificial intelligence have been especially critical to the development of self-driving cars, drones, and other forms of robots. Tesla's electric cars, for example, are constantly streaming performance data into the cloud where AI technology is continually analyzing the data, "learning" from it to improve self-driving technology, and downloading the lessons learned virtually simultaneously so that all Teslas learn from the experience of all the other Teslas. Unlike previous vehicles which begin to fall behind technologically the day they are produced, every Tesla is continually upgraded and therefore more capable over time.

More generally, the car itself is becoming a node in the Internet of Things, including connections within the car and of the car to other cars and to traffic systems as well as infotainment systems. The car is thus becoming a mobile, Internet-connected, AI-powered computer - a mobile smartphone. "From a pure data point of view, the car itself is another 'thing' in the grand scheme of the IoT – just a node on a network. In the IoT, the car is literally a big data in motion problem. The connected car is likely to become the poster child of the IoT revolution because it is part of a wider system of systems (encompassing not only cars but also cities, physical infrastructure, retail, insurance and many others) and leverages key IoT enabling technologies, such as sensors, analytics, big data, natural language processing and cloud computing. The modern connected car – with around one million lines of software code and producing up to 25GB of data every hour – has the potential to create a dazzling array of new digital service possibilities."[45]

Self-driving cars will have an enormous transformative impact on society, from the loss of jobs for taxi and truck drivers to radical revision of urban infrastructure and urban life. The impact on society could be a sharp reduction in driving accidents and fatalities, more than 90 percent of which are due to human error. The second- and third-

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[44] Kevin Kelly, *The Inevitable: Understanding 12 Technological Forces that Will Shape Our Future* (New York: Viking, 2016), p. 29. Kelly notes as an example that AI has been added to enable advanced photography on smartphones. "Contemporary phone cameras eliminated the layers of heavy glass by adding algorithms, computation, and intelligence to do the work that physical lenses once did...Now cognified photography is something almost any device can do as a side job." P. 34.

[45] IBM Center for Applied Insights, "Digital disruption and the future of the automotive industry," October 2015, https://www-935.ibm.com/services/multimedia/IBMCAI-Digital-disruption-in-automotive.pdf.

order effects could include a radical change in how humans use cars, the transportation infrastructure and land use in cities. Sixty percent of urban land is now used by cars for driving and parking, but cars on demand summoned by apps could be in constant use, drastically reducing the need for parking spaces as well as the overall number of cars. This could in turn lead to a redesign of cities and a transformation of urban life styles. In addition, increasing numbers of people are likely to eschew ownership of personal vehicles, which are idle 90 percent of the time, for access to on-demand vehicles, eliminating the cost of purchase, maintenance, parking, and insurance. The benefits of electric, self-driving cars may be even greater for the congested, crowded, polluted, and fast-growing urban areas of the developing world, which are likely to add some two billion more residents over the next three decades. As electric cars become cheaper than internal combustion engine cars and the additional expense of self-driving capabilities also declines to a few hundred dollars, AVs could enable developing countries to leapfrog building "Los Angeles's" of freeways and parking lots and build more sustainable and livable urban environments at lower economic, environmental and social cost.

Industrial robots, powered by many of the same exponential technologies as self-driving cars. are coming out of the factory to work directly with people. The new robots are no longer the encaged industrial robot of the twentieth century -- large, expensive, dangerous, and engaged in repetitive motions assembling vehicles and other heavy machinery. Exponential technologies have led to the development of much cheaper and more capable robots that can work with humans in manufacturing and other tasks. Both the hardware and software costs of the new robots have plummeted. For example, "the single-axis controller, a core component of most robots' inner workings, has fallen in price from $1,000 to $10. The price of critical sensors for navigation and obstacle avoidance has fallen from $5,000 to less than $100."[46] The cost of AI and other software for controlling robots is also falling rapidly. The robots are also part of the IoT, connected to the cloud and learning from each other to continually improve their performanc. More dramatically, robots, including software assistants like Siri on the iPhone, are becoming more and more capable in voice recognition and response. Robots and other machines will be increasingly easy to operate through voice interaction, reducing the amount of training and technical knowledge necessary for humans to work productively and safely with robots.

Cheaper, more capable robots that can work alongside humans are bringing manufacturing closer to the point of consumption. "Right now we think of manufacturing as happening in China," according to Rodney Brooks, founder of Rethinking Robotics, maker of the Roomba vacuum cleaner and the people-friendly Baxter robot.[47] "But as manufacturing costs sink because of robots, the costs of transportation become a far greater factor than the cost of production. Nearby will be cheap. So we'll get this network of locally franchised factories, where most things will be made within five miles

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[46] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), p. 88.
[47] Rodney Brooks Interviewed by Kevin Kelly, The Inevitable: Understanding the 12 Technological Forces that Will Shape our Future (New York: Viking, 2016), p. 53.

of where they are needed." These robotic platforms have evolved at a rate over the last four decades similar to that plotted by Moore's Law. The future is one of ever smarter, more capable—and dramatically less expensive—robots inserting themselves into every corner of people's lives.[48]

The cost of drones also has fallen exponentially in the last few years as their capabilities have increased with smartphone technology. Drones, like robots, have been around for decades, however. Like the first robots of the industrial age, the first drones were large, expensive, and not as capable. For more than a decade, the US military has used drones like Global Hawk and Predator for reconnaissance and combat in Afghanistan, Iraq, and many other countries. But the costs and size of drones have shrunk dramatically in recent years, powered by Moore's law. Cheap, powerful, and light computers and sensors have lowered drone costs and enabled exponentially faster processing of the payloads. "You can buy a Parrot AR.Drone, for example, for about $200 on Amazon. This quadcopter transmits 720p high-definition video to the iPad or smartphone controlling. It is equipped with a three-axis accelerometer, gyroscope, and magetometer, as well as pressure and ultrasound sensors," which two or three decades ago would have cost hundreds of thousands of dollars.[49]

These small quadcopter drones are now being employed for an increasing number of tasks beyond recreational uses. These include commercial delivery of packages, being developed by Amazon, and sending high-value items like vaccines to rural areas in developing countries as well as mail delivery in Switzerland, pioneered by a startup company, Matternet.[50] Hundreds of delivery drone companies are starting up all over the world. In 2015 reportedly 4.3 million drones were shipped as the drone market grew at a rate of 167%.[51] Drone delivery in cities could significantly reduce congestion and pollution by taking delivery trucks off the street and performing jobs that are hazardous for humans like inspecting bridges, cell phone towers, and roofs as well as performing surveillance for fire spotting in rural and forested areas.

Since drones are already so cheap and getting cheaper, they could enable developing countries to leapfrog in development with startups providing the wide range of services emerging in developed countries plus addressing some of the developing world's more difficult challenges, such as delivering supplies to conflict areas, refugee camps, and rural areas with poor ground transportation networks. "In sub-Saharan Africa and parts of Asia, for example, such a service could be critical, because

[48] Robert A. Manning, "Rising Robotics and the Third Industrial Revolution," Atlantic Council, June 2013, http://www.atlanticcouncil.org/publications/issue-briefs/rising-robotics-and-the-third-industrial-revolution.
[49] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), pp. 114-115.
[50] Laura Kolodney, "Matternet cleared to fly blood samples in delivery drones over Swiss cities," Techcrunch.com, March 31, 2017, https://techcrunch.com/2017/03/31/matternet-cleared-to-fly-blood-samples-in-delivery-drones-over-swiss-cities/. See also, Jillian D'Onfro, "Meet The Startup That's Using Drones To Change The World," Business Insider, November 18, 2014, http://www.businessinsider.com/matternet-uav-delivery-drones-2014-11#ixzz3Ig0J3zLW.
[51] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), p. 113.

unreliable transport networks can cause the supply of spare parts for farm equipment or medical equipment to take weeks or months."[52] Inexpensive Drones will also provide new and cheap capabilities for precision agriculture, including monitoring the growth of weeds and crops, spraying insecticides, and monitoring soil hydration. Enterprising startups could "Uberize" drones, providing such services on demand to many farmers at an affordable rate.

3D Printing Almost Anything, Anywhere

3D printing (also known as additive manufacturing) has also benefitted from the "smartphone" technologies and Moore's Law to become cheaper and more capable. It is becoming a "general-purpose technology" that is transforming many industries simultaneously, from health and medical devices to manufacturing and construction. 3D printing is a way of making things - generally layer by layer - that is accomplished by many different techniques, on a wide variety and resolution of machines, with a vast array of materials, and for a huge range of purposes.[53] Many technologies have converged to exponentially enhance the capabilities of a technology that was invented three decades ago. These technologies include advanced computing software for design that is increasingly incorporating AI; internet connectivity and cloud computing; new materials and combined materials, many of which can only be used in additive manufacturing processes; lasers, actuators and new motors; and IoT sensors.

The 3D printing revolution has been the result of a wide range of businesses and individuals pursuing these technologies. Top global manufacturers such as General Electric, Boeing, EADS, and Ford are using expensive 3D printing machines and moving from rapid prototyping to producing critical parts for airplanes, automobiles, wind turbines, and other machines. The 3D printing revolution also has been driven from the "bottom up" by the "do-it-yourself" (DIY) movement, with hundreds of thousands of users buying personal 3D printers for experimentation or starting their own mini-manufacturing enterprises. 3D bioprinters are being used by Organovo and other startup companes to print human tissue and eventually will be able to print new human organs using the patients own cells to eliminate rejection. Many companies are now developing 3D printing for construction of housing and other buildings and infrastructure, greatly reducing cost, building time, labor, and waste - and in some case using recyled concrete to further reduce environmental impact as well as cost.

3D printing technology has also gone to space. Made-in-Space, a small startup, developed the first 3D printer on the International Space Station (ISS) in 2014 and a second one in 2016. MIS is now developing for NASA a robotic 3D printing system that manufacture in the vacuum of space to potentially build huge structures like antenna

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[52] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), p. 116. Wadhwa notes that UNICEF is considering testing drone delivery of medical samples to remote regions of Malawi.

[53] For background and implications of 3D Printing, see Thomas Campbell, Christopher Williams, Olga Ivanova, and Banning Garrett, "Could 3D Printing Change the World?", Atlantic Council, October 2011, http://www.atlanticcouncil.org/images/files/publication_pdfs/403/101711_ACUS_3DPrinting.PDF.

and solar arrays and eventually elements of a new space station and structures on the moon and Mars.[54] 3D printing is also being applied to satellites. Exponential technologies have also made possible development of small, cheap, and capable satellites, including "cubesats," which are 10-centimeter cubes with various possible sensors powered by the guts of a smartphone. Hundreds of cubesats have already been deployed and now MIS and NanoRacks have partnered to produce cubesats on demand on the ISS. The key components will be stored on the ISS and the design for a satellite can be emailed to the printer, which will manufacture the case and the satellite assembled and deployed directly into orbit from the Space Station.[55] Developing nations, businesses, and even universities can afford to deploy custom cubesats, costing around $100,000, that can be used for monitoring crops, environmental damage, surveillance and many other purposes.

3D printing, other advanced manufacturing technologies, and robotics are disrupting supply chains and global trade as well, a trend that is likely to continue to build momentum and disrupt multiple sectors over the next five years and beyond. 3D printing is eliminating more and more of the individual parts needed to make products and enabling customized production of some entire products at the point of consumption.[56] This is reducing the need for extensive supply chains and bringing production closer to the consumer for on-demand production at the point of consumption.[57] "For a rapidly growing number of product categories, 3D printing fundamentally changes the supply chain risk management planning assumption that supply chains are necessarily global and highly complex, and that the fundamental building block of all solutions is visibility. Over time, 3D printing will collapse these multi-tier supply chains."[58]

3D printing is hastening changes in the global economy to bring manufacturing closer to the point of consumption. Manufacturing platforms for export are likely to be eliminated in some cases and reduced in importance in others. "Less labor-intensive 3D-printing operations, combined with the opportunity to manufacture to order and deliver on demand, will dramatically tip the calculus on whether to onshore or offshore manufacturing toward reshoring," in the estimate of supply chain expert Wayne

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[54] Banning Garrett, "Startups Upending Space Industry, Accelerating Space Exploration: Part I: Making Stuff in Space," *EconVue*, October 18, 2016, https://econvue.com/pulse/startups-upending-space-industry-accelerating-space-exploration-part-i-making-stuff-space.

[55] Banning Garrett, "Startups Upending Space Industry, Accelerating Space Exploration: Part II: Proliferating Cheap Satellites," *EconVue*, October 19, 2016, https://econvue.com/pulse/startups-upending-space-industry-accelerating-space-exploration-part-ii-proliferating-cheap.

[56] See the analysis by Christopher H. Lim and Tamara Nair, "How 3D Printing Could Disrupt Asia's Manufacturing Economies," *The Wire*, 14 January 2017, https://thewire.in/99688/3d-printing-disrupt-asias-manufacturing-economies/.

[57] See Wayne Caccamo, "3D Printing Blows Up Supply Chain Risk Management," *Supply and Demand Executive*, August 17, 2016, http://www.sdcexec.com/article/12241583/3d-printing-blows-up-supply-chain-risk-management.

[58] Wayne Caccamo, "3D Printing Blows Up Supply Chain Risk Management, August 5, 2016, http://www.sdcexec.com/article/12241583/3d-printing-blows-up-supply-chain-risk-management.

Caccamo .[59] This will affect transportation sectors as the need for shipping products diminishes, reducing the need for container shipping and air freight.[60]

More and more digital files of products will be sent around the world by email and "rematerialized" at the local level in advanced manufacturing facilities. UPS and SAP have recently partnered to create 3D printing/advanced manufacturing facilities that can produce a wide range of products and parts on demand, based on digital files sent to the facility and delivered locally by UPS.[61] This could include spare parts for planes, trains, and heavy machinery that currently constitute multi-billion dollar business opportunities for DHL, UPS, Fedex and other shipping companies that deliver spare parts from the manufacturer in Europe or the US to service machinery all over the world. This will reduce the time to repair as well as the need to maintain large inventories of spare parts or the need to restart production lines for out-of-stock parts. The US military is already heavily invested in 3D printing for spare parts on ships and at forward bases as well as for enhanced capabilities, new designs, and reduced cost in production of new equipment and weapons systems.[62] 3D printing is also transforming manufacturing processes in the auto industry as well as construction, urban planning and other shared sectors.[63]

Health Care and Medicine: Better, Cheaper, Faster

AI, 3D printing, and other exponential technologies are beginng to have a profound impact on the health sector, greatly reducing costs of diagnosis and preventive medicine as well as medical treatments. 3D printing is already being used for manufacturing human prosethetics that are designed specifically for the individual and are much cheaper to produce as well as human tissue and, eventually, replacement organs.

Not only can human cells and other biological material be bioprinted into tissues and organs, but now life itself - DNA - can be digitized and sent to a bioprinter to be rematerialized - or a new organism not available in nature created, according to Craig Venter. Venter helped pioneer sequencing the human genome, which took more than a

[59] Wayne Caccamo, "3D Printing Blows Up Supply Chain Risk Management, August 5, 2016, http://www.sdcexec.com/article/12241583/3d-printing-blows-up-supply-chain-risk-management.

[60] See Gillian Tett, "Shipping's Globalization Woes," Financial Times, January 14, 2016, https://www.ft.com/content/c9c465de-ba0e-11e5-bf7e-8a339b6f2164#axzz3xLFyUKQF.

[61] "UPS, SAP Team for 3D Printing Network," *RapidReady*, June 16, 2016, http://www.rapidreadytech.com/2016/06/ups-sap-team-for-3d-printing-network/; See also SAP video: https://www.youtube.com/watch?v=aYoNd2nQqLg&t=1s.

[62] See, for example, John Joyce, "Navy Officials: 3D Printing To Impact Future Fleet with 'On Demand' Manufacturing Capability," *Defense Video Imagery Distribution System*, May 18, 2016, https://www.dvidshub.net/news/198483/navy-officials-3d-printing-impact-future-fleet-with-demand-manufacturing-capability#.Vz8q7JMrJMM. See also Yasmin Tadjdeh, "Navy Beefs Up 3D Printing Efforts with New 'Print the Fleet' Program," *Military.com*, October 17, 2014, http://www.military.com/daily-news/2014/10/17/navy-beefs-up-3d-printing-efforts-with-new-print-the-fleet-pro.html.

[63] See David Drake, "5 Industries that 3D Printing Disrupts Most," Hedge Fund Blogs From HedgeCo.Net, January 19, 2017, http://www.hedgeco.net/blogs/2017/01/19/5-industries-that-3d-printing-disrupts-most-by-david-drake/.

decade and cost nearly $3 billion to sequence the first human genome in 2001.[64] The cost of sequencing a complete human genome has fallen faster that Moore's law and now costs about $1,000 and is expected to cost no more than a regular blood test in the early 2020s and eventually almost nothing.[65]

A new organism does not need to be built from scratch. The 3D printing process allows the designer of a synbio product to work with preexisting modules of the product. Synthetic biologists can work, for example, with BioBricks that can be bought and downloaded. BioBricks are DNA constructs of different functioning parts that can be assembled to create new life forms to perform specific functions.[66] The building-block devised design can be sent to a bioprinter that will assemble the genetic material (like the plastics, metals, etc., in a conventional 3D printer) to create a new life form. The creator of the organism will not have to be knowledgeable about how each of the BioBricks works—just as the designer of a 3D printed object does not have to be a software engineer—but only trained to use software to design the object on a computer and send it to the printer. This digital life or organism - or vaccine -- can be transmitted over the Internet and the organism recreated anywhere on the planet.

Venter also notes that genetically engineered organisms also can be created for biofuels, water purifying, textiles, food sources, and bioremediation. British scientist and architect Rachel Armstrong foresees synbio-developed "protocells" transforming architecture and cities to make them more resilient and even positive contributors to the environment. "Instead of our buildings remaining inert, they could adapt to or respond to the seasons, like parks and gardens, with living coatings responding to the availability of more or less wind, sunlight and water." [67]

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[64] See *Life at the Speed of Light* by Craig Venter, who pioneered genome sequencing and creation of artificial organisms. A 2013 report by the National Research Council (NRC) and National Academy of Engineering (NAE) on synthetic biology notes that "while synthetic biology arises from a century's work in biology and related fields...its practice would not be possible without breakthroughs in such diverse fields as engineering, computer science, and information technology." The report emphasizes that "progress in computer and Internet technology revolutionized the ability to process and transfer data and provided ideas and methods for how to manage complexity when engineering multi-component integrated systems. Calculations that only a decade ago would have taken weeks on a mainframe computer now take minutes: a gene sequence may be processed on a laptop." National Academy of Engineering and National Research Council, *Positioning Synthetic Biology to Meet the Challenges of the 21st Century: Summary Report of a Six Academies Symposium Series* (Washington, DC: National Academies Press, 2013), http://www.nap.edu/catalog.php?record_id=13316.

[65] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), pp. 123-124.

[66] The BioBricks Foundation (http://biobricks.org/) maintains a registry of a growing collection of genetic parts that can be mixed and matched to build synthetic biology devices and systems. BioBrick standard biological parts are DNA sequences of defined structure and function that share a common interface and are designed to be incorporated into living cells such as E. coli to construct new biological systems. Many of these parts are created through the International Genetic Engineered Machine Competition (iGEM) of young scientists and engineers. The non-profit company Addgene is another source of downloadable molecular tools. See Heidi Ledford, "CRISPR: gene editing is just the beginning," *Nature,* March 7, 2016, https://www.nature.com/news/crispr-gene-editing-is-just-the-beginning-1.19510.

[67] Rachel Armstrong, Living Architecture: How Synthetic Biology Can Remake Our Cities and Reshape Our Lives, (TED Books: February 6, 2013), Kindle edition.

CRISPR is a new and inexpensive tool that is transforming gene editing for both human medicine and genetic modification of plants and animals.[68] CRISPR allows for highly specific gene editing that allows the researcher to snip target DNA and limit "off target" impact. It is also incredibly cheap. "Unlike previous gene editing systems which could cost thousands of dollars, a relative novice can purchase a CRISPR toolkit for less than US$50." Addgene, a nonprofit supplier of scientific reagents, has shipped tens of thousands of CRISPR toolkits to researchers in more than 80 countries, and the scientific literature is now packed with thousands of CRISPR-related publications.[69] CRISPR gene editing, DNA sequencing, big data and AI are making possible a new era of personalized medicine. The large amounts of data gathered on are "enabling scientists to identify key genetic predispositions to more than 5,000 of the inherited diseases resulting from mutations in a protein-encoding gene" and to target therapies based on the signature of different mutations.[70]

AI is also helping doctors diagnose diseases, including IBM's "Watson," which famously won Jeopardy! in 2012, and since has been developed by IBM for a wide range of intelligence augmentation tasks, including cancer diagnosis. "Watson pores over all the literature, studies a myriad of drug interactions, and sifts through treatment outcomes for patients with similar genetic makeup, background, and cancer strains to identify the best possible course."[71] This will make doctors smarter and let them focus more on the aspects of medicine that require judgment and human touch and interface.

Watson and similar AIs will be available globally, accessible by mobile devices, including to patients. Moreover, digital diagnostics with smartphone sensors is poised to transform preventive medicine and diagnostics and to potentially lower the cost of health care significantly. Smartphones can be used to monitor heart rates and other vital functions, data which is sent to the cloud for analysis and can be used to signal the user to see a doctor or provide diagnosis and suggest remedies or preventive health care steps. Smartphone cameras can be used to photographic the user's skin and upload the photos for AI comparisons with data bases to check for anomalies that could suggest skin cancer or other health problems. Sensor attachments for smartphones are being developed to act as electrocardiograms (ECGs). Even for DNA sequencing, "ultimately, someone will build a sensor-packed dongle and smartphone application that can do it in the field, in seconds: prick your finger; parse you DNA; done."[72]

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[68] "In Just a Few Short Years, CRISPR Has Sparked a Research Revolution," Futurism.com, May 28, 2017. https://futurism.com/just-few-short-years-crispr-sparked-research-revolution/.
[69] Heidi Ledford, "CRISPR: gene editing is just the beginning," *Nature,* March 7, 2016, https://www.nature.com/news/crispr-gene-editing-is-just-the-beginning-1.19510.
[70] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), pp. 126-127.
[71] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), p. 127.
[72] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), p. 124. See also p. 76 on the plummeting cost of delivering high-quality health care by "cutting the doctor entirely out of the loop for initial detection and diagnosis" for many conditions and illnesses.

Exponential technologies are making possible these and many other advances in preventive health care and medical diagnosis and treatment. Many of these technologies, especially daily use of smartphone sensors and cloud-based AI assessment of the uploaded data, could substantially improve preventive medicine as well as direct patients to detect and receive medical treatment at an early stage rather wait for a worsening condiction or an annual checkup that sends to a doctor.

AI assessments of big data sets of anonymized patient data is enhancing the accuracy of diagnosis and the personalization of treatment, which should improve health outcomes and lower costs. "Medicine is becoming an information technology and advancing at an exponential rate," according to Vivek Wadhwa. Moreover, he argues, these technologies "will serve to democratize the standard of care by making our smartphones our diagnosticians, our cardiologists, and our medical labs. The reduction in cost of gene sequencing will bring this capability easily into the realm of affordability for all."[73]

Education: Lower Cost, Higher Quality

Connectivity, mobile Internet access, and artificial intelligence promise increased availability of expansive and personalized educational opportunities on a global scale. Current technology-enabled teaching models, such as the Khan Academy,[74] Udacity, Coursera, Udemy, and the many university-sponsored MOOCs (massive open online courses), are often free or inexpensive, and enable countries to rapidly educate their populations without the huge investment and time-consuming construction of "bricks and mortar" educational institutions and the transportation infrastructure needed to get students physically to the place of education.

These models are reaching only a relatively small number of potential learners, however. Their audience is limited by lack of access to affordable broadband connectivity and mobile devices. Besides lack of broadband connectivity, new technologies, including immersive virtual reality, avatars, and artificial intelligence are still being developed. Nevertheless, it is evident that "we are moving toward a technology-enabled era of learning in which every individual gets what he or she specifically needs and in which the pupils, with A.I. help, largely teach themselves," although human teachers will remain essential. When this vision is realized, then "anyone with an Internet connection can gain access not only to information and coursework (as we can now) but also to a top-notch education. The children of the richest and of the poorest will learn using the same tools and the same A.I., just as the

[73] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), p. 78.
[74] See Thomas L. Friedman, *Thank You for Being Late: An Optimist's Guide to Thriving in the Age of Accelerations* (Farrar, Straus and Giroux: New York, 2016), pp. 227-230.

children of the richest and of the poorest use similar smartphones for communications and social media."[75]

Is Productivity Growth Slowing?

Some experts maintain there has been a secular decline in productivity due to declining innovation that will likely continue into the future and that will negatively affecting job growth. Other experts maintain that productivity is near historic highs in advanced industries utilizing technology while those industries and firms that fail to fully exploit technology are lagging far behind. A third group of experts suggests that current criteria for measuring productivity are deeply flawed and fail to account for all productivity growth.

Robert Gordon maintains that "narrow" technological breakthroughs have had far less impact on productivity in the last decade than the inventions of the late 19th Century.[76] He notes that productivity growth has slowed since 1970, with a slight uptick between 1994 and 2004, reflecting the impact of the internet. The big period of productivity growth was 1920-1970, when output per hour rose at nearly 3% per year. This mid-Twentieth Century productivity spurt, according to Gordon, reflected technology innovations after 1870. The innovations in this period included an energy revolution with the exploitation of oil; the harnessing of electricity and the development of the internal combustion engine; the birth of the chemical industry; and transformative developments in the supply of clean water and sewage disposal.[77] "These led in turn," Gordon writes, "to the creation of machines: the electric light, the telephone, the radio, the refrigerator, the washing machine, the automobiles and the aircraft. They led to the transformation of lives via urbanization and the grid-connected home. These then drove an education revolution, as the economy demanded literate and disciplined workers."[78] By comparison, Gordon argues, the years since 1970 have seen relatively small changes in high-income countries, with an internet-led productivity spike between 1994 and 2004.

The decline in productivity has not been uniform across the US economy, however, and the most technologically advanced industries, have increased productivity at close to the 3% rate of the 1920-1970 period, according to a study by the Brookings Metropolitan Program, "The 50 R&D- and STEM-worker intensive industries that compose America's advanced industry sector have increased aggregate productivity by

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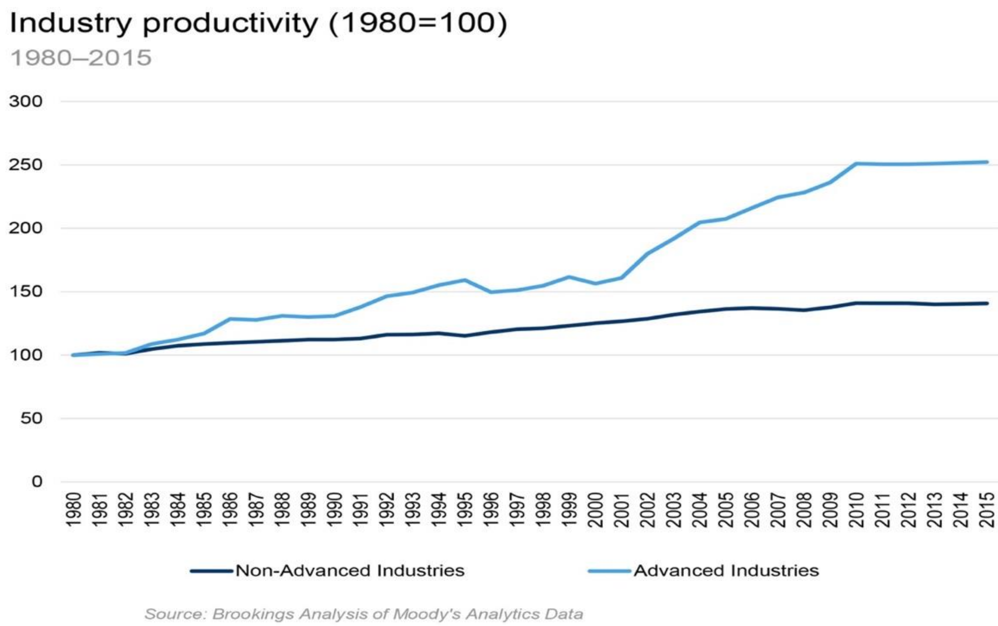
[75] Vivek Wadhwa with Alex Salkever, *The Driver in the Driverless Car* (Oakland, CA: Berret-Koehler Publishers, 2017), pp. 55-56.
[76] Robert Gordon, The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War (Princeton: Princeton University Press, 2016).
[77] Martin Wolf, "An End to Facile Optimism about the Future," *Financial Times*, July 12, 2016, https://next.ft.com/content/5d10878a-4788-11e6-8d68-72e9211e86ab. Robert J. Samuelson cites a new study indicating the as much as 1.2% decline in GDP growth can be linked to aging of US society and probably in other countries as well. "Are aging and the economic slowdown linked?," *Washington Post*, August 21, 2016, https://www.washingtonpost.com/opinions/are-aging-and-the-economic-slowdown-linked/2016/08/21/ffd6b270-6626-11e6-96c0-37533479f3f5_story.html?utm_term=.12a1c7f1a3da.
[78] Gordon's argument summarized by Martin Wolf, "An End to Facile Optimism about the Future," *Financial Times*, July 12, 2016, https://next.ft.com/content/5d10878a-4788-11e6-8d68-72e9211e86ab.

about 2.7 percent a year since 1980—far, far faster than the rest of the economy, which has increased productivity growth by only 1.4 percent a year."[79]



Metropolitan Policy Program at BROOKINGS

Moreover, "U.S. advanced industries are now, on average, more than twice as productive as non-advanced industries, given that each worker in an advanced industry generates approximately $214,000 worth of output compared with $103,000 for the average worker in other industries. The starkness of that gap—and the fact that huge industries like health, education, and leisure and hospitality manage productivity levels of no more than $61,000, $49,000, and $41,000 per worker—sheds important light on the nation's productivity problem."[80] In addition, these more productive workers also receive is a wage premium - and this is the case at all levels of education.

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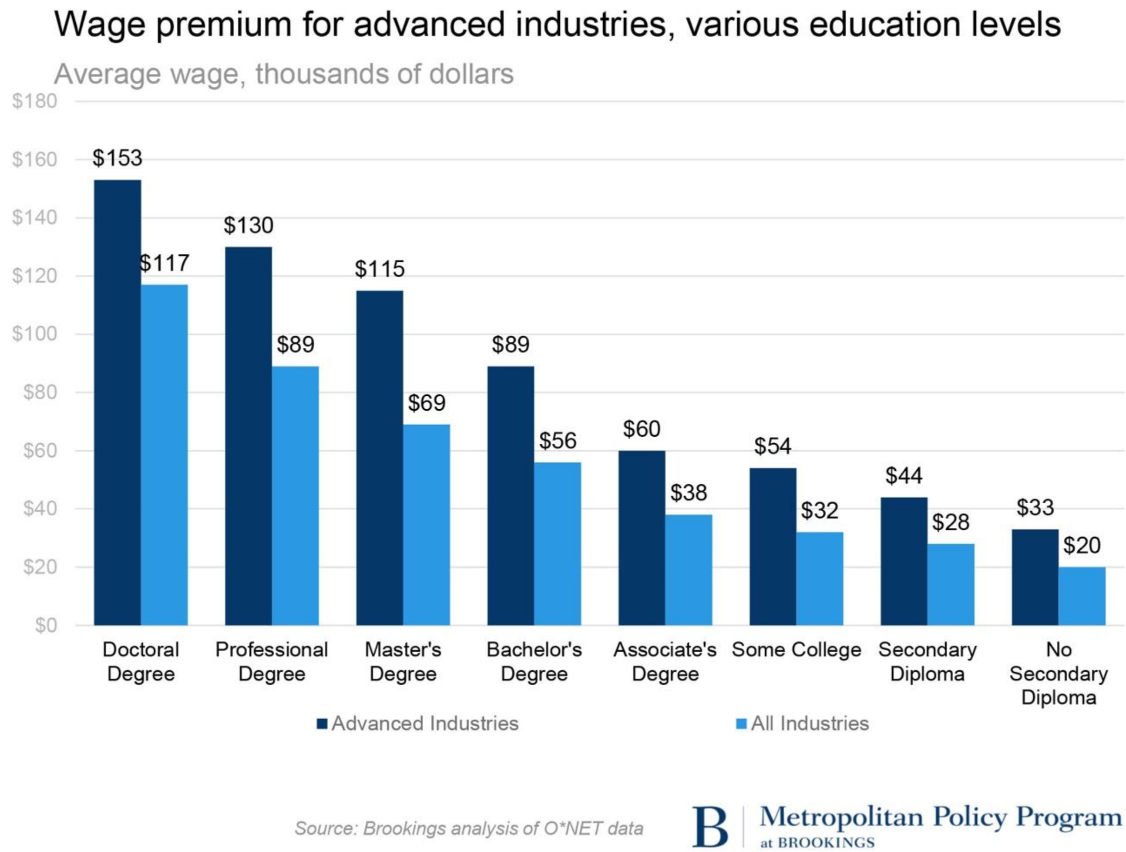
[79] Mark Muro, "Look to Advanced Industries to Help Drive Productivity Gains," Brookings, Advanced Industries Series | Number 94, July 21, 2016, http://www.brookings.edu/blogs/the-avenue/posts/2016/07/21-productivity-gap-advanced-industries-muro?utm_campaign=Brookings+Brief&utm_source=hs_email&utm_medium=email&utm_content=31965590&_hsenc=p2ANqtz-_jypkBZI2_JmObfvlBTI95mCS_QV7yWFtgi4joGadgy9Fw-ufFkSj1ZQzn56KHNj1ZSv3JKAe_-jmXzQOxTUDSHtuKbQ&_hsmi=31965590.

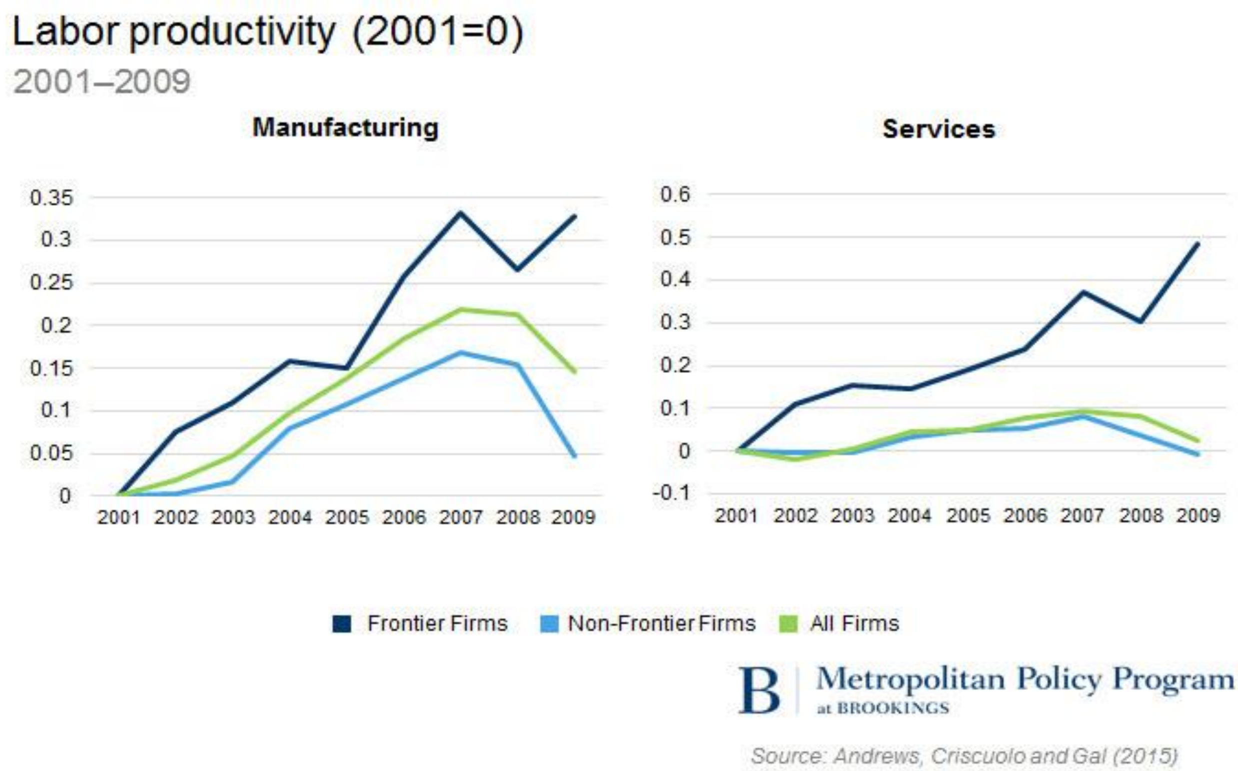
[80] Mark Muro, "Look to Advanced Industries to Help Drive Productivity Gains," Brookings, Advanced Industries Series | Number 94, July 21, 2016, http://www.brookings.edu/blogs/the-avenue/posts/2016/07/21-productivity-gap-advanced-industries-muro?utm_campaign=Brookings+Brief&utm_source=hs_email&utm_medium=email&utm_content=31965590&_hsenc=p2ANqtz-_jypkBZI2_JmObfvlBTI95mCS_QV7yWFtgi4joGadgy9Fw-ufFkSj1ZQzn56KHNj1ZSv3JKAe_-jmXzQOxTUDSHtuKbQ&_hsmi=31965590.



The Brookings report also notes that "frontier" firms within industries are far more productive than non-frontier firms. "Staying with the advanced industries data, advanced manufacturing firms generate some $216,000 worth of output per worker while non-advanced manufacturing concerns generate just $102,000. Likewise, recent OECD research[81] concludes that the 100 most globally productive "frontier" firms in each relevant industry are on average four to 10 times more productive than non-frontier firms, depending on which productivity measurement is employed."[82]

[81] Dan Andrews, Chiara Criscuolo and Peter N. Gal, Frontier Firms, "Technology Diffusion and Public Policy: Micro Evidence from OECD Countries," *The Future of Productivity: Main Background Papers*, OECD, 2015, http://www.oecd.org/eco/growth/Frontier-Firms-Technology-Diffusion-and-Public-Policy-Micro-Evidence-from-OECD-Countries.pdf. The study noted: "Despite the slowdown in aggregate productivity, productivity growth at the global frontier remained robust over the 2000s. At the same time, the rising productivity gap between the global frontier and other firms raises key questions about why seemingly non-rival technologies do not diffuse to all firms. The analysis reveals a highly uneven process of technological diffusion, which is consistent with a model whereby global frontier technologies only diffuse to laggards once they are adapted to country-specific circumstances by the most productive firms within each country (i.e. national frontier firms)."

[82] Mark Muro, "Look to Advanced Industries to Help Drive Productivity Gains," Brookings, Advanced Industries Series | Number 94, July 21, 2016, http://www.brookings.edu/blogs/the-avenue/posts/2016/07/21-productivity-gap-advanced-industries-muro?utm_campaign=Brookings+Brief&utm_source=hs_email&utm_medium=email&utm_content=31965590&_hsenc=p2ANqtz-_jypkBZI2_JmObfvlBTI95mCS_QV7yWFtgi4joGadgy9Fw-ufFkSj1ZQzn56KHNj1ZSv3JKAe_-jmXzQOxTUDSHtuKbQ&_hsmi=31965590.



Mark Muro of the Brookings Metropolitan Policy Program concludes that the problem in the United States "is not so much a slowing of productivity growth in its most productive industries and firms, but rather a slowing of the pace at which productivity spreads from frontier industries and firms to far larger, but lower-productivity industries that represent the vast majority of the economy." Moreover, "many industries and firms have abundant room to boost productivity. Notwithstanding those like Gordon who see little hope for significant improvements, the productivity deficits of huge, low-performing industries and the majority of U.S. firms show where to look for the gains that can improve all Americans' standards of living."

The problem is not the spread technology destroying jobs, Muro argues, but rather that "to generate gains, a national, state, local, and industry productivity push should seek to foster further innovation at the frontier and encourage faster diffusion of advances across industries." Moreover, "policy and industry leaders should seek to accelerate technology and upgrade lagging industries, such as through investments in digitization, as is now happening in health and education industries." In sum, Muro argues, the productivity crisis is not total. "Progress continues at the frontier; it's the drift elsewhere that is the problem. Looking forward, the challenge is going to be in transferring gains at the edge to the rest of the economy."[83]

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[83] Mark Muro, "Look to Advanced Industries to Help Drive Productivity Gains," Brookings, Advanced Industries Series | Number 94, July 21, 2016, http://www.brookings.edu/blogs/the-avenue/posts/2016/07/21-productivity-gap-advanced-industries-muro?utm_campaign=Brookings+Brief&utm_source=hs_email&utm_medium=email&utm_content=31965

Technology jobs also generate more jobs in local demand for services, not only in the United States and other developed countries, but also in developing countries. "It is estimated that one additional technology job creates around five new jobs in the local non-tradable sector" in developed economies and that the multipliers for skilled manufacturing jobs range as high as 16 in South Africa and 21 in India, according to Frey and Rahbari.[84] "It would therefore be misleading to focus merely on the job-destroying effects of technology or indeed only take into account those directly created by technology sectors. … the same technological advances that threaten jobs and development models also bear unprecedented possibilities to boost productivity, reduce poverty, and improve the efficiency of public services."

Martin Wolf of the *Financial Times* also notes that much of the US economy is resistant to rapid increase in productivity. He notes that in 2014 "fully two-thirds of US consumption went on services, including rent, healthcare, education and personal care," which are sectors where the problem is not that all the jobs are going to disappear "but rather that it is hard to make them do so. That shift in the composition of output towards sectors where it is hard to raise productivity is a big reason for the slowdown."[85] These sectors, which make up an increasing share of the US economy, are the sectors least transformed by technology.

There is also a question of whether productivity is being accurately measured in the era of the digital economy. Zachary Karabell argues that perhaps the entire framework for measuring productivity is flawed and that productivity may be far higher than official economic statistics maintain.[86] "The hard numbers today are clearly failing to account for certain observable contradictions -- such as how there can be high levels of employment combined with very little wage growth and extremely low inflation. If various free or inexpensive digital solutions are generating adequate output without adding much in the way of labor costs or capital spending, then that would explain why labor costs and capital investment are low. And if those solutions are also leading to less expensive goods and services, that would in part explain why measured productivity is weak. A cheaper digital solution leading to cheaper and more efficient goods doesn't do much for GDP or corporate revenue, but it meets collective needs just as much as a labor- or capital-intensive solution leading to more output and higher labor productivity." Moreover, "slower measured productivity isn't having the same consequences as when the economy was primarily based on making physical goods" since "the deflationary effects of technology can both improve standards of living and lower GDP." A long-distance domestic phone call several decades ago could cost

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590&_hsenc=p2ANqtz-_jypkBZI2_JmObfvlBTI95mCS_QV7yWFtgi4joGadgy9Fw-ufFkSj1ZQzn56KHNj1ZSv3JKAe_-jmXzQOxTUDSHtuKbQ&_hsmi=31965590.

[84] Carl Benedikt Frey and Ebrahim Rahbari, "Do labor-saving technologies spell the death of jobs in the developing world?" Brookings Institution, prepared for Brookings Blum Roundtable 2016, https://www.brookings.edu/wp-content/uploads/2016/07/Global_20160720_Blum_FreyRahbari.pdf.

[85] Martin Wolf, "An End to Facile Optimism about the Future," *Financial Times*, July 12, 2016, https://next.ft.com/content/5d10878a-4788-11e6-8d68-72e9211e86ab.

[86]See Zachary Karabell, "The Real Problem with Productivity is Measuring It," Bloomberg View, May 22, 2017, https://www.bloomberg.com/view/articles/2017-05-22/the-problem-with-productivity-is-measuring-it.

$1.00/minute and $5.00/minute or more for an international connection. These costs added to GDP. Now video calls globally are free via Skype. They add nothing directly to GDP although they may greatly enhanced business communications and productivity as well as improve the lives and lower the "cost of living" for individuals.

Innovation: from "Top Down" to "Bottom Up"

Traditional economic models may also miss the current and future significance of the democratization of technology and innovation. "Top down" models of innovation are being challenged by more chaotic, "bottom up" processes, including "startups" outside or inside companies as primary sources of new ideas and inventions. Larger corporations are frequently turning to acquisition of startups as they are unable to generate the same quality of innovation internally as their "immune systems" reject change and innovation.[87] This has been seen in big pharma for years and now in artificial intelligence as Google, Facebook, Intel, Baidu, and other major technology companies acquire promising startups to both bring the "best and brightest" into their tent and to deny that talent to their competitors.

The democratization of technology by enabling startups to be formed anywhere for a few thousand dollars or less, even in biotechnology, is powering this bottom up innovation. Startups are far more flexible and are generally far cheaper than in-house innovation, which faces high costs of personnel and overhead and often many bureaucratic and cultural obstacles, including aversion to risk. As cloud computing, open-source software, and, increasingly, AI have become cheap "utilities" accessible by anyone with a laptop computer, the democratization of technologies has a small group of entrepreneurs nearly anywhere on the planet to access technologies such as massive server farms and advanced AI that previously would have been available only to large corporations, research institutes, and governments. Even biology experiments and new inventions can be uploaded to the cloud without incurring the costs of owning expensive laboratory equipment.

Is "De-Industrialization" a Threat to Developing Countries?

Economists have warned that manufacturing jobs in emerging market and low-income countries are threatened by "premature deindustrialization," driven in part by the "rise of the robots" and by the return of manufacturing to developed countries like the United States. But other trends, including "democratized" technologies, online platforms, and the gig economy might provide alternative sources of economic and employment growth for emerging market and low-income countries.

A slowdown if not halt to industrialization in many developing countries has threatened job growth in developing countries. "What developing countries are

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[87] See Salim Ismail, "Fixing Civilization - Taking on Immune Systems," *Medium*, 21 January 2017 https://medium.com/@salimismail/how-to-fix-civilization-6e0c494f5737#.yuxo9was1 and his book, *Exponential Organizations: Why New Organizations Are Ten Times Better, Faster, and Cheaper than Yours (and What to do about it) (New York: Diversion Books, 2014).*

experiencing today is appropriately called 'premature deindustrialization,'" according to economist Dani Rodrik. "In most of these countries, manufacturing began to shrink (or is on course for shrinking) at levels of income that are a fraction of those at which the advanced economies started to de-industrialize. These developing countries are turning into service economies without having gone through a proper experience of industrialization."[88] Premature deindustrialization, Rodrik maintains, "reduces the economic growth potential and the possibilities for convergence with income levels of the advanced economies" since formal manufacturing tends to be technologically the most dynamic sector. "Deindustrialization removes the main channel through which rapid growth has taken place in the past."

The consequences of premature deindustrialization are already visible in the developing world, according to Rodrik. In Latin America, as manufacturing has shrunk, the informal economy has grown and economy-wide productivity has suffered. In Africa, urban migrants are crowding into petty services instead of manufacturing, and despite growing Chinese investment there are as yet few signs of a real resurgence in industry. "Where growth occurs, it is driven largely by capital inflows, transfers, or commodity booms, raising questions about its sustainability. In the absence of sizable manufacturing industries, these economies will need to discover new growth models." [89]

The World Bank, using the Frey-Osborne methodology, estimated that the share of jobs at risk of automation is higher in developing than in developed countries—77 percent and 69 percent of all jobs in China or India, respectively—and perhaps 85 percent in Ethiopia, against an average 57 percent of jobs in OECD countries. [90] Frey and Rahbari note, however, that "since this methodology only reflects the technological capabilities and does not take into account differential labor costs, it should not be interpreted as implying that automation is likely to replace jobs even faster in developing countries than in industrial ones." Nevertheless, developing economies are by no means insulated from automation trends that may hinder their ability of developing economies to use their labor-cost advantage to build prosperous economies and societies over time.[91]

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[88] Dani Rodrik, "Premature Deindustrialization," Institute of Advanced Studies, School of Social Science, Economics Working Paper Number 107, January 2015, https://www.sss.ias.edu/files/papers/econpaper107.pdf, p. 3. For Rodrik's explanation of premature deindustrialization, see pp. 1-6. Rodrik notes that the term "premature deindustrialization was first used by Dasgupta, Sukti, and Ajit Singh, "Manufacturing, Services and Premature Deindustrialization in Developing Countries: A Kaldorian Analysis," UNU-WIDER, United Nations University Research Paper, No. 2006/49, 2006.

[89] Dani Rodrik, "Premature Deindustrialization," Institute of Advanced Studies, School of Social Science, Economics Working Paper Number 107, January 2015, https://www.sss.ias.edu/files/papers/econpaper107.pdf, p. 23.

[90] Carl Benedikt Frey and Ebrahim Rahbari, "Do labor-saving technologies spell the death of jobs in the developing world?" Brookings Institution, prepared for Brookings Blum Roundtable 2016, https://www.brookings.edu/wp-content/uploads/2016/07/Global_20160720_Blum_FreyRahbari.pdf.

[91] Carl Benedikt Frey and Ebrahim Rahbari, "Do labor-saving technologies spell the death of jobs in the developing world?" Brookings Institution, prepared for Brookings Blum Roundtable 2016, https://www.brookings.edu/wp-content/uploads/2016/07/Global_20160720_Blum_FreyRahbari.pdf.

Frey and Rahbari report that the "hollowing out" by premature deindustrialization has been visible across a large number of developing countries, including Macedonia, Turkey, Mexico, and Malaysia, according to Frey and Rahbari.[92] The most notable exception to this trend has been China, which "may be one of the last countries to ride the wave of industrialization to prosperity" and is now the world's largest acquirer of industrial robots to replace workers.

Industrialization peaked in Western European countries such as Britain, Sweden, and Italy at income levels of around $14,000 (in 1990 dollars), according to Rodrick, while "India and many sub-Saharan African countries appear to have reached their peak manufacturing employment shares at income levels of $700."[93] Industrialization enabled catch-up and convergence with the West by a relatively smaller number of non-Western nations, including Japan starting in the late 19th century, South Korea, Taiwan and a few others after the 1960s, Rodrik notes. But "for countries that still remain mired in poverty, such as those in sub-Saharan Africa, future economic hopes rest in large part on fostering new manufacturing industries."[94]

Thus "premature" deindustrialization "is not good news for developing nations," according to Rodrik, as "it blocks off the main avenue of rapid economic convergence in low-income settings, the shift of workers from the countryside to urban factories where their productivity tends to be much higher."[95] Premature deindustrialization is a result in part of new technology that is leading to "reshoring" of manufacturing in developed countries. "Technological breakthroughs of the 20th century—such as the container ship and the computer— significantly contributed to the rise of global supply chains, enabling companies to locate production where labor is cheap. Yet, recent developments in robotics and additive manufacturing, or '3D printing,' have made it increasingly economical for companies in advanced countries to 'reshore' production to mostly automated factories," according to Frey and Rahbari.[96]

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[92] Carl Benedikt Frey and Ebrahim Rahbari, "Do labor-saving technologies spell the death of jobs in the developing world?" Brookings Institution, prepared for Brookings Blum Roundtable 2016, https://www.brookings.edu/wp-content/uploads/2016/07/Global_20160720_Blum_FreyRahbari.pdf.
[93] Dani Rodrik, "Premature Deindustrialization," Institute of Advanced Studies, School of Social Science, Economics Working Paper Number 107, January 2015, https://www.sss.ias.edu/files/papers/econpaper107.pdf, p. 15.
[94] Dani Rodrik, "Premature Deindustrialization," Institute of Advanced Studies, School of Social Science, Economics Working Paper Number 107, January 2015, https://www.sss.ias.edu/files/papers/econpaper107.pdf, p.1.
[95] Dani Rodrik, "Premature Deindustrialization," Institute of Advanced Studies, School of Social Science, Economics Working Paper Number 107, January 2015, https://www.sss.ias.edu/files/papers/econpaper107.pdf, p.23. See also Carl Benedikt Frey and Michael Osborne, "Technology at Work: The Future of Innovation and Employment," *Citi Global Perspectives and Solutions*, February 2015, https://www.citivelocity.com/citigps/ReportSeries.action?recordId=49&src=Home, p .62.
[96] Carl Benedikt Frey and Ebrahim Rahbari, "Do labor-saving technologies spell the death of jobs in the developing world?" Brookings Institution, prepared for Brookings Blum Roundtable 2016, https://www.brookings.edu/wp-content/uploads/2016/07/Global_20160720_Blum_FreyRahbari.pdf.

Countries in East and Central Africa as well as parts of Southeast Asia that were once poised to replace China as the world's next low-end manufacturing base will be further disadvantaged by reshoring of manufacturing by developed countries, in the view of Rebecca Keller of Stratfor's *Geopolitical Weekly*. "States that have not yet begun to industrialize will have the hardest time; the longer it takes them to develop over the next few decades, the more difficult it will be for them to do so as the growth of advanced manufacturing elsewhere shrinks the opportunities available for emerging manufacturers. Developing an advanced industrial base takes additional capital, skills and time, essentially increasing the number of rungs separating low-end and high-end manufacturers on the production value ladder."[97]

This may not be the whole picture, however. Emerging market and low-income countries may benefit from some of the same technologies and innovation trends that have led to premature deindustrialization and reshoring as developed countries bring manufacturing home with advanced manufacturing technology. These countries don't have factories and factory workers to lose their jobs to automation. They can leapfrog to 3DP factories, to a range of democratized technologies for agriculture and services as well as distributed water purification and energy production - all of which could offer new opportunities for job creation, especially small entrepreneurial enterprises and support for small-scale businesses, including in agriculture. Frey and Rahbari comment that "it would therefore be misleading to focus merely on the job-destroying effects of technology or indeed only take into account those directly created by technology sectors. … the same technological advances that threaten jobs and development models also bear unprecedented possibilities to boost productivity, reduce poverty, and improve the efficiency of public services.[98]

Conventional views of the impact of technology on jobs may fail to adequately appreciate the new business and job opportunities provided by global digital platforms built on the Internet -- opportunities for emerging market and low-income countries as well as for developed countries. Martin Ford predicts that "the new industries that emerge will nearly always incorporate powerful labor-saving technology right from their inception," noting that companies like Facebook and Google, with huge reach and massive evaluations, have a tiny number of employees.[99] Frey and Osborne quantify this, noting that "according to a recent estimate, the three leading companies of Silicon Valley employed some 137,000 workers in 2014 with a combined market capitalization of $1.09 trillion. By contrast, in 1990 the three largest companies in Detroit had a market capitalization of $36 billion while collectively employing about 1.2 million workers."[100]

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[97] Rebecca Keller, "The Rise of Manufacturing Marks the Fall of Globalization," Stratfor *Geopolitical Weekly*, June 7, 2016, https://www.stratfor.com/weekly/rise-manufacturing-marks-fall-globalization.
[98] Carl Benedikt Frey and Ebrahim Rahbari, "Do labor-saving technologies spell the death of jobs in the developing world?" Brookings Institution, prepared for Brookings Blum Roundtable 2016, https://www.brookings.edu/wp-content/uploads/2016/07/Global_20160720_Blum_FreyRahbari.pdf.
[99] Martin Ford, *Rise of the Robots* (New York: Basic Books, 2015), p. xvi.
[100] Carl Benedikt Frey and Michael Osborne, "Technology at Work: The Future of Innovation and Employment," Citi Global Perspectives and Solutions, February 2015, https://www.citivelocity.com/citigps/ReportSeries.action?recordId=49&src=Home, p. 7.

But this is not the complete picture. These companies may have few employees, but they are platforms for huge numbers of people engaged in business and generating jobs.

Facebook commissioned Deloitte to estimate the economic impact it enabled in 2014 around the world. Deloitte's analyzed the contribution Facebook supports as a catalyst for economic activity in ecosystems composed of marketers, app developers, and providers of connectivity.[101] The report estimated that "through the channels of marketers, app developers and providers of connectivity, Facebook enabled $227bn of economic impact and 4.5m jobs globally in 2014. These effects accrue to third parties that operate in Facebook's ecosystem, and exclude the operations of the company itself. The United States is estimated to capture the largest share of economic impact enabled, $100bn; high rates of engagement enabled $21bn of economic impact in Central and South America; the thriving app economy in EMEA (Europe, Middle East, and Africa) has helped to generate $13bn of economic impact for the region through the platform effects; and In APAC (Asia Pacific) internet uptake and purchases of devices motivated by Facebook have contributed to $13bn of economic impact."

While assessing the future impact of new technology on economic growth and job creation is difficult, it is useful to consider the extraordinary growth of the Internet over the past 20 years and the exponential increase in its use and its economic impact. Just 20 years ago, in 1996, approximately 45 million people were using the Internet, with roughly 30 million of those in North America (United States and Canada), 9 million in Europe, and 6 million in Asia/Pacific (Australia, Japan, etc.). 43.2 million (44%) U.S. households owned a personal computer, and 14 million of them were online."[102] Internet users in 1996 thus constituted less than 0.8% of the global population of 5.7 billion. By 2016, there were 3.6 billion Internet users out of a total global population of 7.34 billion, 49.2% of the global population -- an increase of 8000% of online users over 20 years.[103] The impact of the internet on economic growth and jobs has been huge and growing. Even by 2011, when there were only 2 billion internet users,[104] McKinsey concluded, the

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[101] Deloitte, "The global economic impact of Facebook: Helping to unlock new opportunities," http://www2.deloitte.com/uk/en/pages/technology-media-and-telecommunications/articles/the-global-economic-impact-of-facebook.html. Deloitte, "Facebook's Global Economic Impact," January 2015, http://www2.deloitte.com/uk/en/pages/technology-media-and-telecommunications/articles/the-global-economic-impact-of-facebook.html, p. 1. "Google's search and advertising tools helped provide $165 billion of economic activity for 1.4 million businesses, website publishers and non-profits," in the United States in 2015, according to "The web is working for American businesses. Google is helping." "Economic Impact, 2015," Google, https://economicimpact.google.com/#/. The report compiled by Google claims that: 1.4 million nationwide businesses and non-profits benefitted from using Google's advertising tools, AdWords and AdSense, in 2015.1 75% of the economic value created by the Internet is captured by companies in traditional industries. $165 billion of economic activity Google helped provide nationwide for businesses, website publishers and non-profits in 2015. Two times as many jobs and twice as much revenue through exports were created by web-savvy SMBs. 97% of Internet users look online for local products and services. 9 out of 10 part-time business owners rely on the Internet to conduct their businesses.

[102] "Internet Timeline," *Factmonster*, http://www.factmonster.com/ipka/A0193167.html.

[103] "Internet Users in Top 20 Countries vs. the World, June 30, 2016, *Internet World Stats*, http://www.internetworldstats.com/top20.htm.

[104] "Number of Internet users worldwide reaches two billion, *Physics.org*, January 26, 2011

web contributed 3.4 percent to GDP in the 13 countries covered by the research -- the G-8 nations as well as Brazil, China, India, South Korea, and Sweden -- which was "an amount the size of Spain or Canada in terms of GDP, and growing at a faster rate than that of Brazil" and, if measured as a sector, was by that time bigger than agriculture or energy.[105] It is likely that the Internet's impact on economic growth and job creation has continued to increase in absolute numbers as well as a proportion of the global economy.

The technology of the internet and the many platforms built on this "platform of platforms" are creating new opportunities for entrepreneurs and SMEs to reach global markets at a time when globalization in trade and capital flows is stalling. While trade in traditional goods and services is flat, a study by the McKinsey Global Institute shows that cross-border digital flows in areas such as e-commerce, streaming video, web searches and so on have increased 45 times in the past decade, and are projected to grow another nine times in the next five years. What is more, the companies responsible for the jump include a much higher proportion of small businesses and sole proprietors. That points to a form of globalization that could be much more inclusive and thus less politically contentious.[106]

Technology not only can create new businesses that employ more workers but also it can bring new efficiency to local, national, and global job markets by more effectively connecting job seekers to employers. Online digital platforms for both traditional employment and freelance assignments are bringing much greater efficiency to local, national and global job markets by increasingly connecting people to the right work opportunities. According to another 2016 MGI report by the McKinsey Global Institute (MGI), *A labor market that works: Connecting talent with opportunity in the digital age,*[107] individuals, including in developing countries, are "using global digital platforms to learn, find work, showcase their talent, and build personal networks. Some 900 million people have international connections on social media, and 360 million take part in cross-border e-commerce."

These platforms could add $2.7 *trillion*, or 2%, to global GDP by 2025, increasing employment by 72 million full-time-equivalent positions, according to MGI, "and begin to ameliorate many of the persistent problems in the world's labor markets" by easing labor-market dysfunctions to more effectively connect individuals with work

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http://phys.org/news/2011-01-internet-users-worldwide-billion.html.

[105] Matthieu Pélissié du Rausas, James Manyika, Eric Hazan, Jacques Bughin, Michael Chui, Rémi Said, "Internet matters: The Net's sweeping impact on growth, jobs, and prosperity," McKinsey Global Institute, May 2011, http://www.mckinsey.com/industries/high-tech/our-insights/internet-matters.

[106] Rana Foroohar, "Uberisation and the Dangers of Neo-Serfdom," Financial Times, 9 August 2016, https://www.ft.com/content/2dd6d524-5d53-11e6-bb77-a121aa8abd95?ftcamp=crm/email//nbe/techFT/product.

[107] James Manyika, Susan Lund, Kelsey Robinson, John Valentino, and Richard Dobbs, "Connecting talent with opportunity in the digital age," *McKinsey Global Institute Report*, June 2015, http://www.mckinsey.com/global-themes/employment-and-growth/connecting-talent-with-opportunity-in-the-digital-age. Full executive summary is at: file:///Users/banninggarrett/Downloads/MGI%20Online%20talent_A_Labor_Market_That_Works_Executive_%20summary_June%202015%20(1).pdf.

opportunities. “Such platforms include websites, like Monster.com and LinkedIn, that aggregate individual résumés with job postings from traditional employers, as well as the rapidly growing digital marketplaces of the new ‘gig economy,’ such as Uber and Upwork.”

While hundreds of millions of people around the world already use these services, their capabilities and potential are still evolving. As online talent platforms grow in scale, MGI predicts, they will become faster and more effective clearinghouses that can inject new momentum and transparency into job markets while drawing in new participants. In countries around the world, 30 to 45 percent of the working-age population is unemployed, inactive in the workforce, or working only part time. In just seven countries -- Brazil, China, Germany, India, Japan, the United Kingdom, and the United States -- this adds up to 850 million people, according to MGI.

Labor markets around the world have not kept pace with rapid shifts in the global economy, according to the MGI report. “Many who do work feel overqualified or underutilized. Online talent platforms can ease a number of these dysfunctions by more effectively connecting individuals with work opportunities.” MGI maintains that “up to 540 million people could benefit from online talent platforms by 2025,” including as many as 230 million who could find new jobs more quickly, reducing the duration of unemployment, and another 200 million who are inactive or employed part time who could gain additional hours through freelance platforms. “As many as 60 million people could find work that more closely suits their skills or preferences, while an additional 50 million could shift from informal to formal employment.” The greatest beneficiaries of these online talent platforms are countries with persistently high unemployment and low participation rates such as Greece, Spain, and South Africa.

A combination of digital platforms and the sharing economy is also creating new companies and jobs. Zipcar co-founder Robin Chase calls this “Peers Inc.”, the title of her 2015 book that explores transformation from industrial to collaborative capitalism.[108] “Google, eBay, Facebook, OKCupid, YouTube, Waze, Airbnb, WhatsApp, Duolingo— all are part of this transformation of capitalism,” according to Chase. “Web 2.0, the sharing economy, crowdsourcing, collaborative production, collaborative consumption, and network effects are simply terms we’ve created along the way in an effort to capture what is going on.” She maintains that there “one structure that underlies all these— excess capacity + a platform for participation + diverse peers— and it is fundamentally changing the way we work, build businesses, and shape economies,” combining “the best of people power with the best of corporate power” to use “every resource and every stakeholder efficiently.”

Building Science, Technology, and Innovation Capacity

[108] Robin Chase, *Peers, Inc.: How People and Platforms Are Inventing the Collaborative Economy and Reinventing Capitalism* (New York: Public Affairs Books, 2015, Kindle Edition). pp. 1-2.

Humans have used every technology destructively as well as constructively, from the harnessing of fire and the invention of the wheel to the development of nuclear weapons and nuclear power - and now the Internet and cyberhacking and cyberwarfare. New and emerging technologies pose a wide range of dangers from error or intentional misuse. Some experts worry that artificial intelligence could pose an existential threat to humanity. Others point to the dangers of gene editing, including the possibility of creating "super humans," and potential engineering of the deadly pathogen through bioerror or bioterror. Realistically, every new technology has not only the potential for misuse but the likelihood that it will be misused by someone, somewhere. The global community must seek to mitigate the dangers while preserving the benefits of scientific research and technological development. Regarding artificial intelligence and human gene editing, for example, there are a wide range of experts and institutions who are taking such threats seriously and seeking to develop guidelines for research and use of these powerful new technologies.[109]

Internet connectivity is a *sine qua non* for all key technologies, from digital platforms like Facebook and Google and app stores like iTunes and Google Play, to the functioning of smartphones, autonomous vehicles, drones, robots, cloud computing, the IOT, AI, VR, AR, gene editing and computational biology, and the development of new materials and nano-technology. Thus, the bottom line for all nations seeking to harness these technologies for development and achieving the SDGs is building out making broadband mobile Internet accessible and affordable for all citizens. To secure the benefits of the Internet, all nations have a high-priority interest in global cooperation to protect the security and functionality of the global Internet.

Building capacity to exploit the new technologies to meet the challenge of the SDGs will need to be a high priority for all countries, including national and sub-national governments, business, NGOs, and all levels of educational institutions. Education at all levels will be critical, including: STEM education beginning in primary school; STEM vocational training and apprenticeships; and steps to encourage and create the

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[109] Concerns about AI, for example, have been met with new institutions like OpenAI (https://openai.com/) and the Future of Life Institute (https://futureoflife.org/) by the Beneficial AI Conference at Asilomar in January 2017 of many of the world's top AI experts to create a set a principles to guide AI research, development, and use (https://futureoflife.org/ai-principles/). The National Academy of Sciences and the National Academy of Medicine organized an International Summit on Human Gene Editing (http://www.nationalacademies.org/gene-editing/Gene-Edit-Summit/index.htm) in December 2015 with the Chinese Academy of Sciences the Royal Society of the United Kingdom and to explore the potential dangers as well of gene editing in light of new technologies, including CRISPR (http://www.sciencemag.org/news/2015/12/embryo-editing-make-babies-would-be-irresponsible-says-dna-summit-statement; see also a report on the meeting, http://www.sciencemag.org/news/2015/12/inside-summit-human-gene-editing-reporter-s-notebook). An international panel convened by the National Academy of Sciences released a report with its recommendations on human gene editing in February 2017 (https://www.nytimes.com/2017/02/14/health/human-gene-editing-panel.html). The availability of cheap lab equipment also could lead to "home brewed" lethal viruses that could unleash at global pandemic for which there was no antidote or vaccine. See Laurie Garrett, "Staying Safe in Biology Revolution," July 11, 2013, Council on Foreign Relations video, http://www.cfr.org/technology-and-science/staying-safe-biology-revolution/p31087.

infrastructure and opportunities for lifelong STEM learning to meet the demands for jobs of the future as well as of the present. Education and training will have to go beyond STEM to include a wide range of soft skills from business management and entrepreneurialism to city planning and management. It will also have to include cultural development to encourage good work habits and behavior - a challenge for many depressed areas in the United States.[110] All levels of government, including top political leaders and heads of bureaucracies, need to strongly support increasing science and technology literacy and appreciation of the critical importance of harnessing STI for the SDGs throughout the government and society.

National and local governments will also need to support and nurture innovation ecosystems, from incubators and accelerators to public-private partnerships (PPPs) with large corporations to best harness technologies to meet the SDGs. In addition, government, PPPs, and venture capital as well international capital and financial instruments will be needed to support developing and scaling technological solutions. Finally, the public at large needs to be included in defining problems and finding solutions.

In "going to where the puck will be," stakeholders should plan for the new tools to be provided by technology that will advance technology's potential for achieving the SDGs. These include not only educational tools like on-line courses, but also new tools like augmented reality and virtual reality. In addition, AI and other advances are making new technology increasingly user-friendly. Natural Language Processing (NLP) combined with AI (and developed through the use of ML) will make "talking" with machines easier, more intuitive, and more powerful. Even illiterate people will have increasing ability to utilize a wide range of technologies. If one thinks smartphones, it is easy to understand that relatively uneducated people can utilize a huge range of apps and other smartphone functionalities even they have a very limited understanding of how the smartphone works. AI and NLP are likely to make an increasing number of machines and services increasingly accessible to an increasing number of people with limited formal education. This emerging environment should offer a wide range of new possibilities for employment, productivity, and governance as nations pursue the SDGs, especially increasing inclusivity and creation of good jobs.

The Future Promises both Disruptions and Opportunities

One relative certainty is that the future will not simply be an extrapolation of the present. The worlds of 2025 and 2035 are likely to be discontinuous with the present, especially as a result of new technologies such as artificial intelligence and robotics, which will be applied to a huge variety of businesses and other technologies as AI becomes a utility and the world is wired up by the Internet of Things. These and other technologies will be hugely disruptive throughout society, from the lives of individuals to

[110] See Thomas L. Friedman, "A Road Trip Through Rusting and Rising America," *New York Times*, May 24, 2017, https://www.nytimes.com/2017/05/24/opinion/rusting-and-rising-america.html?action=click&pgtype=Homepage&clickSource=story-heading&module=opinion-c-col-right-region&region=opinion-c-col-right-region&WT.nav=opinion-c-col-right-region&_r=1.

the fate of businesses, the restructuring of cities, and the activities and organization of governments. The discontinuities and disruptions will have profound implications for jobs, the nature of work, and society as a whole.

The democratized technologies available globally are creating very low cost-of-entry for entrepreneurs to create new companies and other organizations and governments to apply these technologies and draw on the huge base of platform users. By 2025, nearly every person on the planet will have access to the extraordinary capabilities of internet-connected mobile devices. This will include free access to the Global Positioning System for geolocation, including the use of GPS to integrate geolocation into their commercial apps and websites to enhance their business prospects.

These new digitally-enabled exponential technologies may enable low-income and emerging market countries to “leapfrog” stages of development, like the cell phone enabled these countries to bypass extensive investment in “landlines” as the developed countries had done decades earlier. 3DP printing,[111] inexpensive robots and internet connectivity could enable countries with few factories and factory workers at risk of technological unemployment to create millions of new jobs -- one small startup “factory” at a time -- that could be linked with many other technology-platform-enabled, small-scale but scalable enterprises of the “sharing economy.” Moreover, distributed energy systems, especially solar PV, and distributed water purification systems could enable small businesses built around these technologies to rapidly scale to meet societal needs. In addition, a wide range of advanced but democratized technologies can enable small-holder farms to enlist 21st Century technologies to greatly enhance productivity and linkages to markets.[112]

New technology, science, and innovation is coming together to bring production of food and meat to urban regions, at potentially great cost savings, environmental dividends, and new jobs producing and distributing the food.[113] These trends could lead to transformation of the economies of cities and states, not just in the developed world but also in emerging market and low-income countries, to become more economically and environmentally sustainable. The overall impact of accelerating technological change in the coming decade could be the beginning of a dramatic restructuring of the world economy that will move toward production of goods, food, and energy closer to where they are consumed, reducing and even eliminating many supply chains, while

[111] See, for example, building 3D printers and businesses in Tanzania: http://allafrica.com/stories/201601220625.html.
[112] For discussion of the technologies that will transform agriculture over the next twenty years, both eliminating and creating jobs, see Agriculture and Food Development Authority, Government of Ireland, “Technology Transforming Irish Agri-food and Bioeconomy 2035,” https://www.teagasc.ie/media/website/publications/2016/Teagasc-Technology-Foresight-Report-2035.pdf.
[113] Grace Phillips Ogilby of 1776.vc, for example, maintains that “if done right, aquaponics and vertical farming technologies could have massive implications for the price of food in terms of both dollars and resource depletion.” Grace Phillips Obilby, “The Fishy of Urban Aquaponics, 1776.vc, August 19, 2016, http://www.1776.vc/insights/urban-aquaponics-vertical-farming-fish-startups/?mc_cid=fe3cdaa125&mc_eid=196eeb7c4a.

also accelerating a Third Industrial Revolution beyond the developed economies, creating millions of new jobs through increased productivity and economic growth.[114] This could be an economy of "just in time production at the point of consumption" that could include large multinationals operating as platforms and partners to local, scalable enterprises.

Connectivity -- from affordable and universal broadband internet access and cheap mobile devices to global flows and openness -- will also be crucial to maximize possibilities for capitalizing on technology to create jobs, enhance productivity, and produce sustainable growth. The use of the smartphone should be instructive for scoping the possibilities for job creation. There are very few people on the planet who understand all the workings of a smartphone, but there are about 3 billion people who know how to use this extraordinary apparatus for an amazing array of functions, many directly relevant to work, including geolocation, information access and retrieval, email and messaging, Facebook posting of economic and other business information, ride hailing and other ecommerce functions, translation, accessing thousands of servers for AI enabled functions, and many, many other tasks.

Nascent trends could become major transformative factors by 2025, including the gig economy and economic transformation utilizing democratized technologies. Development of the "sharing" or "gig" economy and support for startups and SMEs using advanced technologies and digital platforms will ring out inefficiencies in the economy and government while creating jobs. Global economic transformation is underway built on new technologies, especially platforms that create opportunities for bringing technology innovations to local economic development in cities and to increase productivity and sustainability in agriculture. Renewable energy and distributed energy systems will not only power communities but also create many local jobs, directly and indirectly. New technologies are also enabling economically viable production of food in urban vertical farms and with 3D printed foods and meats. Seizing such opportunities will depend significantly on adoption of business-friendly regulations, building 21st Century infrastructure, increasing availability of capital, including for startups and SMEs, and overall good governance.

Achieving the UN's 17 Agenda 2030 Sustainable Development Goals (SDGs) could entail massive job creation drawing on advances in technology, thus driving application of new technology for job-creating purposes to build infrastructure and the built environment of cities (including with 3D printing, advanced materials, IOT sensors and cloud-based systems for gathering and analyzing the IOT data, robotic construction equipment, autonomous vehicles, etc.), advanced agriculture to feed the population, health care systems with digital medicine and other technologies, new educational models with MOOCs and other technology-enabled learning systems, etc. Moreover, tens of trillions of dollars in infrastructure investment over the next few decades will create millions of construction jobs, many of which will involve application of new technologies such as 3D printing and smart cities technologies.

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[114] Some analysts are calling it the "fourth" industrial revolution. See, for example, Klaus Schwab, *The Fourth Industrial Revolution* (Geneva: World Economic Forum, 2016).

Policy Propositions and Recommendations

Governments need to recognize and act on these ten critical propositions:

1. the pace of technological change is accelerating exponentially
2. exponential technologies offer new opportunities to address old and new problems with “better, cheaper, faster, and scalable” solutions
3. exponential technologies are democratizing access to advanced technology with exponentially declining costs and exponentially rapid diffusion around the world
4. exponential technologies are disrupting industries, business models, and government operations
5. achieving many, if not most, of the SDGs will require harnessing these exponential technologies with innovation, entrepreneurship, and government support
6. cheaper, scalable solutions to accelerate development will enable governments to “do more with less” to stretch limited resources
7. democratized technologies allow experimentation and “failing fast” with minimal investment, avoiding “lock in” to large, expensive, long-term, and potentially obsolete projects
8. affordable and accessible broadband internet connectivity is the foundation for capitalizing on exponential technologies, from manufacturing to health care to government services
9. accelerating technological change will impact and disrupt nearly all aspects of society, from the economy, education, and jobs, to culture, national security, and politics.
10. the next two decades are likely to experience more technology-induced change than in the last 50 years or more

Governments need to transform their operating models to take advantage of the accelerating technological revolution underway. This includes:

- educating government officials at all levels of national, provincial and local government about scientific, technological and engineering advances that are disrupting the economy and government and providing new opportunities
- recruiting scores of talented scientists and technologists to work throughout government to bring both S&T literacy and perspectives to government policymaking
- establishing or strengthening government S&T offices to research and educate the government and public about available advances in science and technology and “best practices” for their use to provide solutions for their own governments, communities, and businesses
- transforming government to become less hierarchical and bureaucratic and more innovative flexible, open, and adaptable
- breaking down silos between agencies and departments to enhance information sharing and cooperation in identifying and analyzing problems and opportunities, and to develop and implementing comprehensive solutions

- combatting “immune systems” within government that tend to block innovation and change
- capitalizing on new technological opportunities to improve services and discover and exploit potential efficiencies throughout government
- placing a high priority on providing accessible and affordable broadband internet connectivity to all citizens and businesses as a critical for development, education, and inclusive governance
- exploring “crowd sourcing” for finding solutions to problems and off-loading to the public functions that the public can perform such as pothole spotting that will allow government officials to focus on functions only they can perform
- developing public-private partnerships for addressing a wide range of societal needs, from building physical and IT infrastructure to revamping education
- developing and nurturing innovation ecosystems, including incubators and accelerators, to support entrepreneurs exploiting democratized technologies to build companies that will help achieve the SDGs
- establishing “X Prize” competitions to solve key problems such as providing potable water at very low cost, in the process creating an ecosystem of innovation
- creating new financing models and platforms to finance startup enterprises and small-scale, low-cost experiments and exploit opportunities to “leapfrog” previous steps in development as was done with the cell phone
- employing the internet and social media to enhance transparency of government operations and to solicit citizen involvement in governance and problem solving
- capitalizing on AI to exploit the huge stores of “dark” big data that can provide insights to enhance efficiencies throughout the government and economy
- using development assistance smartly to support a “better, faster, cheaper, and scalable” approach to development to maximize benefit of financial resources while empowering “bottom up” development
- creating “strategic foresight” groups throughout government agencies to inform policymakers about long-term trends and challenges and to identify preferred alternative futures and near-term policy options to achieve desired outcomes
- enhancing awareness and mitigation strategies to cope with the downsides and even potentially dangerous impacts of emerging technologies while also encouraging and supporting the development and deployment of exponential technologies to meet the SDGs

Appendix A: Lessons and Recommendations for Developing and Nurturing Innovation Ecosystems

Alfred Watkins and Banning Garrett

Many developing countries -- as well as developed countries -- have had disappointing results in seeking to leverage incubators, accelerators, and tech parks for economic growth and job creation. World Bank expert Victor Mulas recently sought to explain some of the reasons for this failure.[115] He acknowledged a few significant successes, such as in New York City, “where the connection with local industries has resulted in new jobs, new industries, and greater competitiveness for traditional sectors.” But in other cases, he wrote, “I wonder if the actual — and potential — impact of these emerging start-up ecosystems is being exaggerated and if we are all collectively witnessing an overflow of attention and resources that cannot translate into ‘magic’ solutions to unemployment and other global challenges.”

Noting that the successes of many of the innovation ecosystems “seem to be overinflated,” Mulas concluded that not many start-ups become sustainable businesses, “and the few successful examples are cited over and over again.” The problem, he wrote, is that the start-ups are “disconnected from local industries and there is little absorption of start-up innovation by the economy.”

The challenge, he explained is “setting the right expectations and not overstating them, and, more important, understanding and actively fostering the dynamics that can create sustainable and competitive start-ups over time.”

Innovation ecosystems are not just a matter of providing buildings for incubators and accelerators but rather fostering a much more nurturing supporting environment for startups. The success of all three institutions -- incubators, accelerators, and technology parks -- are based on three common principles.

The first principle is that bringing small technology businesses under one roof where they can interact with each other is better than leaving them to operate in isolation. Propinquity promotes the cross pollination of ideas and knowledge. It also promotes serendipity as an SME working on one problem may gain unexpected insights from an SME working on a totally unrelated problem. Or an entrepreneur developing a technology to solve one problem -- preventing drowning in swimming pools -- through unexpected interactions with other entrepreneurs and their customers, may discover a totally unexpected use for the technology -- filtering water in fish ponds without sucking the baby fish into the filter.

The second principle is that clustering SMEs in one location makes it easier to introduce these companies to VCs, mentors, and business services providers. And the third principle is that locating these institutions adjacent to universities and research institutions (think MIT and Stanford) makes it easier for professors and students to convert their cutting-edge knowledge into successful startups and also to find skilled employees.

These principles are all undoubtedly correct and well known. And yet when developing countries seek to establish incubators, accelerators and technology parks on

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[115] “The start-up bubble: How abundant money is actually not helping,” World Bank, Private Sector Development, blog, 30 November 2016, http://blogs.worldbank.org/psd/start-bubble-how-abundant-money-actually-not-helping.

the basis of these principles, the results are often disappointing at best or abject failures at worst. Why?

What's missing in most cases is any strong link between the companies in the incubator and dynamic companies outside the incubator. All too often, firms in incubators, accelerators and technology parks have few or no inherent links to the broader local economy. As a result, the incubators become enclaves, or islands unto themselves. In Silicon Valley, by comparison, incubators, accelerators and tech parks are so effective precisely because the SMEs in these incubators, technology parks and accelerators have close ties to larger dynamic firms in Silicon Valley and beyond. These larger dynamic firms serve as customers for the technology and ideas produced by SMEs in the incubators. In fact, many of the SMEs in Silicon Valley are spin-offs from these larger firms and were established precisely with the goal of servicing these larger firms. Venture capitalists, meanwhile, are familiar with these larger firms and attempt to invest in companies whose products they believe will be of interest to these larger firms.

All too often, sponsors of incubators in emerging markets focus on the agglomeration benefits while overlooking the importance of establishing close links between companies in the incubator or tech parks, on the one hand, and dynamic companies outside the incubators and accelerators, on the other hand. To establish these links, incubators could focus on supporting SMEs that provide technical, financial, organizational or marketing solutions to local exporters. These exporters can be parts of global value chains -- for example, providing roasted coffee to Starbucks or processed agricultural produce to Walmart, etc. These exporting companies generally tend to be more dynamic than non-exporting local companies, have a relatively secure cash flow, and face competitive pressures to stay on the cutting edge of technology and innovation. Or they can focus on supporting local entrepreneurs who hope to use globally available technology (off-grid refrigeration, nano-filters to generate potable water) to provide affordable, high priority services (potable water, off-grid electricity) on a financially sustainable basis to local consumers. The opportunities are endless, but if they hope to be successful, organizers of incubators and accelerators need to do a better job of tailoring their services to these opportunities.

These principles have been successfully applied in Brazil. For the last four years, Marc Weiss, founder and chair of Global Urban Development (GUD), has been working on sustainable innovation and inclusive prosperity in Porto Alegre, Brazil, and helped establish ZISPOA, a Sustainable Innovation Zone in the city. In an interview, Weiss concluded based on his experience in Brazil that tech parks should be tied to overall strategic economic development requirements of the regional economy, including those of multinational corporations with a local presence. “Tecnopuc” in Porto Alegre attracted Microsoft, Dell, HP, and ThoughtWorks as a good location for international companies to do their business, and nearby "Tecnosinos" similarly attracted SAP and HT Micron. “They liked the region, the city, the transportation connections, the university relationship, and the good ambience for their workforce,” according to Weiss. Moreover, “the multinationals in the tech park created an attractive address for local companies wanting to be co-located." For developing countries, Weiss concluded, "you cannot start a tech park with startups to attract big MNCs. Rather, the MNCs attract local companies and startups. Thus, having a university and an attractive location, both city and region, is the way to attract MNCs. Once you have the MNCs, you can attract major local companies and develop an innovation ecosystem pipeline to generate startups."

Weiss stressed that an innovation ecosystem must be tied to a major university since the students and professors are key to the ecosystem's success. "It needs the dynamism of a university, which becomes a talent pool for a startup culture and for businesses in the tech park and the MNCs in the tech parks to develop a research relationship with the university." Weiss also noted that "both of the tech parks in Porto Alegre have incubators and other programs to sponsor and support startups."

Failure to put the entire package together can lead to disappointing results, according to Weiss, who noted, "the city of Bel Horizonte, Brazil, established a tech park that was not very successful even though it spun off from a major university. The reason for the failure was that they did not attract major IT companies or pharma. The tech park was based mostly on small local companies that have not been strong enough to provide a critical mass. You need mix of major MNCs and local companies and small startups for tech parks to thrive."

Weiss recommends that governments evaluate and enhance the conditions for building an innovation ecosystem. This includes assessment of: the quality of their major university's graduate education, research capabilities, and faculty; available land and facilities for a nearby tech park; the local and potential MNC industry mix that fits the university and the local talent pool; transportation systems; and other conditions attractive to business, including quality of life. "A strategy then can be developed to provide incentives for universities as well as for the companies," Weiss said. "The government can act to strengthen the university and the infrastructure of the region, including transportation. Developing countries' successes with incubators, accelerators, and tech parks replicate this model - the right university, the right strategic location for businesses, the right mix of tech companies in different fields wanting to be there, quality neighborhoods, and an attractive quality of life as well as good infrastructure."